

CURRENT DEVELOPMENT AND FUTURE PROSPECTS OF DESIGNING SUSTAINABLE FASHION

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Abstract:

In recent years, the entire fashion industry has been striving to develop in a more sustainable way. As the starting and crucial link of fashion product development, the process of design plays a decisive role in creating a healthier fashion supply chain. In this sense, the current work discusses from the design point of view the status quo and future direction of the development of fashion sustainability. The paper first describes the concept, the historical development, and the multi-angled significance of sustainable fashion design. Then, the current development of sustainable fashion design is studied by investigating the various ideas and approaches that are popular nowadays for the designing of eco-friendly and waste-free clothing. On this basis, the current work digs into the existing problems and finally points out the future prospects for the development of sustainable fashion design by putting forward some innovative and promising ideas and instructive "future-making" techniques.

Keywords:

sustainability; fashion design; zero-waste; recycling; design management

1. Introduction

Nature is the basis for human survival and development, providing shelter and resources for human beings. Since the Industrial Revolution, people have come to realize that environmental resources are never inexhaustible [1,2]. When people use nature for resources, they have to protect it as well. As terms like "eco-friendly," "green," "bio," "recycling," "ethical," "natural," etc. came into our daily life and attract more and more attention through various social and for-profit media [3], the whole of society has come to realize the significance of pursuing the harmony between social progress and sustainable development by paying more attention to and practicing environmental protection and carrying out ethical discussion about modern production and consumption [4–7].

Sustainability seeks a balance between the natural and unnatural development of human society and has a major impact on the advancement of all walks of our lives under a globalized economy [8]. As one of the most intimate friends to our body, clothing naturally becomes the most natural carrier of our social standing and attitudes [9]. And the fashion industry is gradually becoming a mirror of our modern society, reflecting people's acceptance of new things, and to some extent, indicating the movement of the entire society, and the ever-changing mode of people's physical and psychological lives

[10]. Fashion has often been connected with creativity, change, and taking aesthetic beauty and luxury as priorities, regardless of waste and pollution. Fashion can hardly be described as "green," "eco-friendly," "sustainable," or "ethical" [11]. And for a long time, consumers seem quite able to accept this dazzling and a bit eccentric world for granted, making fast (i.e., quickly produced) fashion and luxurious fashion one of the most profitable industries on the globe [12,13].

As the idea of environmental protection becomes more and more popular over the planet, the public has begun to pay more attention to the relationship between environmental protection and people's ordinary lives [14]. As individuals, we have come to pay more attention to the "eco" and "bio" marks on product bags and tend to think twice during a purchase if the product is suspected of being hazardous to the environment. This positive change also appears in our attitude towards clothing, the use of it, and the fashion industry as a whole [15]. Ordinary consumers start to care about whether the garment is made of natural or synthetic fabrics, especially when it is for underwear use [14]. The life cycle of garments is being increased. Some people even start to think seriously about their purchasing motivation and habits, and try to want less and buy less [16]. Actually, our experience tells us that those clothes that we buy out of temporary desire, or only due to their look or current trends, will quickly be discarded because of ever-changing trends and desires. As people's desire to "waste" is constrained, they are

surprised to find that they finally get more from the environment and deep inside the heart in return. The whole society is more open to discussions on not only environmental ethics [17,18] and animal ethics [19], but also ethical issues concerned with apparel production such as working conditions, labor rights, child labor, etc. [20].

Global textile consumption is increasing every year, which is causing a serious impact on the environment and society we live in [21]. The fashion industry is no doubt one of those that should face and tackle sustainable issues seriously [22,23]. In the pursuit of lower production and labor costs and thus higher overall profits, many apparel companies move their production sectors to developing countries with comparatively weaker awareness of environmental and ethical issues and incomplete environmental laws and regulatory systems [24]. With the awareness of the social values about the harmonious development of humans and the environment, some fashion brands such as Adidas, C&A, Inditex, and Benetton have been blamed for developing their supply chains in an unethical or unsustainable way [25]. In recent years, many fashion companies have started to incorporate “green” practice into their design, production, and marketing strategies [26,27]. Examples include brands such as Uniqlo, Muji, H&M, The North Face, and New Balance [28–30]. Research and utilization of innovative eco-materials have become a hot topic during these years [31]. Sustainable fashion principles and design methodologies from either a practical or philosophical point of view are being paid more attention to and constantly practiced, such as “cradle to cradle” [32], functional design [33], “slow fashion” [34,35] zero waste,[36], handcrafting [37], etc. The recycling of used clothing, second-hand clothing exchange and other means are emerging and developing quickly [38].

Opportunities and challenges always come together. Sustainable fashion design is developing rapidly, but meanwhile, it is facing some problems too. The differences between current fashion practice and sustainability from either an ideological or practical point of view still exist [39–41]. The development of a sustainable fashion supply chain is in its very early stages and will affect different stakeholders such as material suppliers, designers, producers, retailers, and consumers [42]. The safety and security problems concerned with sustainable products also hold back the development of sustainable fashion industry by causing distrust and even panic at the consumer end [15].

No matter what problems sustainable fashion is facing, it is undeniable that design is the key solution to them. Design visualizes sustainable concepts by connecting and sometimes involving links in the supply chain [39], such as material suppliers and production; design factors help carry out direct conversation with consumers, and thus could be one of the best media transmitting sustainable principles and boosting public acceptance [3,14,43]. In essence, fashion is not extreme extravagance or waste, nor is it being simple or frugal. The development of sustainable fashion needs the persistent efforts from the whole fashion chain, especially fashion designers. How to achieve the compatibility of fashion design and sustainability while satisfying consumers' pursuit of fashion

and aesthetics, taking into account the environmental, social and moral factors, should be the pursuit and responsibility of every fashion designer nowadays [44].

Starting from the concept and historical development of sustainable fashion, the current paper analyzes the current status of sustainable fashion design from the perspective of the use of environmentally friendly materials and various currently popular concepts and techniques in sustainable design. On this basis, the future trend of sustainable fashion design is analyzed, and some innovative future design ideas and methods are proposed.

2. Concept of Sustainable Fashion

The essence of the concept of sustainable development is to properly handle the relationship between people and nature in order to achieve the orderly use of resources. Its ultimate goal is to achieve the recycling of resources [45–48]. The World Commission on Environment and Development defines sustainable development as “the development that meets the needs of today's people without compromising the ability of future generations to meet their needs”[49–52]. An up-to-date understanding of sustainability is the “triple bottom line,” which takes into account three aspects: society, environment, and economic performance [53].

With the advancement of technology brought about by industrial development, changes are taking place in all walks of life. The fashion industry is one of the most sensitive industries to witness and respond to social and economic changes. In recent years, fashion consumption and wearing cycles have been shrinking dramatically. In the 19th century, a fashion cycle lasted about 10 years, but the current fashion cycle changes much more quickly, as often as quarterly or even weekly [54]. Fashion markets are oversaturated due to highly effective mass manufacturing and retailing systems. The world is full of discarded and even unsold fashion items. The U.S. consumer disposes of 31 kilograms of textiles and clothing each year, and over 900 million apparel items are disposed of each year in the U.K. [55]. It is estimated that unsold garments may account for up to 10% of the whole of fashion production each year [20].

As the whole society comes to realize that the resulting problems of natural resource shortage, ecological chain destruction, social and economic abnormal development may have a long-term and irreversible impact on human beings, the fashion industry began to recognize the serious necessity of sustainable development on both the supply and demand sides [56]. There goes a saying that “no need, no killing.” Unhealthy and uncontrolled desire seems to be at the root of greed and waste. On the consumption side, the public has begun to reflect on their attitudes and habits of purchasing clothing, and some of them are even trying to adjust their perception of the nature of fashion [57].

However, it is undeniable that there exists a tough conflict between fashion and sustainability due to their respective development processes and connotations. The former is

defined by hedonism and sometimes short product life cycles, especially in fast fashion [27,58] and sometimes huge expense for luxury fashion[59,60], while the latter implies ethics, durability, and the reuse of products [61], which makes it common sense to believe that fashion is quite behind in sustainability [26]. Therefore, introducing sustainable concepts into the fashion industry so as to build an environmentally friendly and healthily running fashion ecology is no doubt a huge, systematic, and thus long-term mission that requires the participation and collaboration of every link in the entire fashion industry chain.

As for now, most of the effective efforts made towards sustainable fashion focus on the control of raw materials such as the use of more environmentally friendly and organic fabrics and findings, design innovations such as zero-waste design and recycling design, and finally, fabric reuse. But these measures are intuitively insufficient to achieve genuinely sustainable fashion. As mentioned above, to fully realize sustainable fashion will need efforts from not only designers in the one-way mode, but also each participant of the fashion industry from suppliers to consumers in the so-called multi-way mode.

3. Overview of Sustainable Fashion Design Development

Since ancient times, human beings have been living in conflict with nature and engaged in “overthrowing the balance of nature for their own benefit” [62]. Early European philosophers believed that in order to make human social life safer and more balanced, human beings as individuals needed to make certain sacrifices [63–65]. This view contains a rudimentary concept of sustainability. It was not until Rachel Carson published *Silent Spring* in 1962 that people first noticed the environmental problems brought about by the development of production forces [66]. From then on to 1980, before the International Union for Conservation of Nature (IUCN) put forward the concept of sustainable development for the first time, human beings did not have a clear goal for the cause of environmental protection [67].

Affected by the energy crisis, the environmental awareness in fashion industry came into being in the 1970s [68]. Victor Papanek, an American designer, pointed out in his book *Design for the Real World* that “designers should be brave enough to shoulder social responsibility rather than pursue commercial interests” [69]. Renowned designers such as Issey Miyake, Giorgio Armani, Oscar de la Renta, and Christian Lacroix created fashions with green materials such as coarse cotton, hemp, grass, and wool; eco-conscious products such as rope sandals and tie-dye T-shirts symbolized the early practice of eco-friendly design and caused a sensation at that time [68,70–72]. The British Designers Association called on their designers to take responsibility to minimize the direct or indirect harm to the ecological environment in their work [73]. The hazards concern those produced in every link of the entire design and production process that directly or indirectly endanger the sustainable and harmonious development of the environment and all kinds of organisms, including plants and animals, air, rivers, and oceans, etc. Colleges and institutes

such as the Academy of Fine Arts of Tsinghua University in China, the London College of Fashion, and the ESMOD International Fashion Design Institute in Berlin have been constantly offering both theoretical and practical courses related to sustainable fashion [50]. Sustainable fashion principles and techniques such as zero-waste design, “cradle to cradle” (C2C) or regenerative design, and slow fashion are gaining global attention [32,34–36]. Collaborative fashion consumption (CFC) modes have emerged recently, which circulate garments through gifting, swapping, sharing, or renting, try to provide consumers with various eco and easy access to fashion products and are subtly changing the public’s attitudes and habits towards fashion consumption [74–76]. Such practices are being more and more accepted by ordinary consumers.

As the green fashion ecosystem gradually takes shape, designers who stand at the origin of product development defining the initial intention and future direction of each piece of fashion item, undoubtedly play a particularly important role in promoting the vigorous advancement of sustainable fashion. Fortunately, the design circle is gradually forming a consensus on sustainable development. Designers are generally aware that in addition to creating economic value with their products, they also shoulder the inescapable social responsibility. In recent years, a large number of fashion brands have begun to invest in sustainable fashion. More and more designers are determined to accept the challenge of sustainable design. They are defining and developing various ways and methods from the starting point of product development to realize the sustainability of the fashion industry [77–78].

4. Expressive Means of Sustainable Fashion Design

At present, sustainable fashion design has three main means of expression: the use of natural and recyclable materials, zero-waste design, and recycling of used garments. These three methods explore the possibility of combining fashion with sustainability by incorporating green and recycling ideas into the critical processes of material sourcing, fabric weaving, garment tailoring, and waste disposal.

4.1. The Use of Environmental Friendly Materials

According to the theory of environmental protection, the main criterion for identifying whether garment materials conform to the ecological concept is whether they will cause damage to the environment in the process of production and waste disposal. According to this standard, along with the wearability requirements of clothing (i.e., the basic requirements on clothing to achieve protection, comfort as one wears it, etc.), good materials for making clothes need at least to be non-toxic, harmless, healthy, and comfortable to wear. The use of toxic chemicals in garment materials should be eliminated or minimized in the planting and manufacturing processes. Meanwhile, it is important to maximize the use of renewable resources and reduce energy consumption. Once a garment is discarded, the material it is made of is expected to be renewable, recyclable, naturally or artificially degradable, thus causing less pollution to the environment [77]. The following

is a brief introduction to the current application of eco-friendly materials in sustainable fashion design.

(1) Natural raw materials

It is commonly accepted that clean and renewable natural materials such as organic cotton, jute, ramie, silk, and wool are the best eco-friendly raw materials for clothing production [79]. Brands like Muji and Uniqlo have long been known for producing and selling clothes made of simple and natural materials and are pioneers in the practice of sustainable fashion [80–81]. Besides, in order to reduce contamination to the environment as well as the raw material itself, non-toxic and harmless (or low toxic and less harmful) measures such as using organic fertilizers and avoiding using poisonous chemical pesticides, are being taken in the planting raw materials for clothing. Brands such as Wal-Mart, C&A, NIKE, People Tree, H&M, and ZARA, etc., use natural fibers produced in organic management in their clothing [82]. In addition, another option could be even more cutting edge and problem solving. Compared with ordinary natural fibers, organic fibers that have been genetically modified (called transgenic fibers) can be planted without the need of chemical fertilizer and pesticide, so there are no chemical residues harmful to the human body [83,84]. All these above measures help to protect the ecological environment by reducing the various resource consumption and contamination caused during by planting, thus they are the mainstream measures taken by the industry to achieve sustainable development from the beginning of fashion production.

(2) Regenerated fibers

In addition to the “organification” of clothing raw materials, the research and development of regenerated fibers are also a mainstream means to make material sustainable and have been applied to the development of new products by many domestic and foreign brands.

Regenerated fibers are created by dissolving the cellulose or protein area of natural substances (usually plants or plant-based materials) in chemicals and making them into fiber again through the viscose method; these are an important subset of man-made fibers [85]. Since they are regenerated from natural cellulose, regenerated fibers are also a mainstream means to realize fashion sustainability from a material perspective, and have been broadly applied by domestic and foreign brands [79,86,87]. For example, as a “green fiber in the 21st century,” Tencel fiber uses wood pulp as a raw material, which causes little environmental pollution during production and recycling, and can be completely recycled. Tencel can be blended with a variety of fibers such as linen and cashmere to emphasize different features. It usually has good performance in softness, moisture absorption, and bacteriostatic properties, and thus is widely used in underwear and casual wear [88].

Regenerated fibers can come from various sources, such as plants, seeds, leaves, skins, fruit, and stalks. Common examples involve cotton, flax, ramie, sisal, jute, hemp, seaweed, bamboo, and wood.[89]. Recent development can be found in

the application of corn fiber, soybean protein fiber, lotus fiber, hismer fiber, banana fiber, and pineapple fiber[90]. An Italian company recently created an orange fiber from citrus juice, whose resulting product was reported to feature a lightweight and silky texture [91]. Another innovation is a natural leather alternative called Pinatex, which is actually a nonwoven textile made from cellulose fibers extracted from waste pineapple leaves, polylactic acid, and petroleum-based resin [92]. Regenerated fibers may vary in performance, being either tough, light or soft, rough or smooth, but they have one thing in common: they cause less pollution to the environment [38,93]. Therefore, these fibers are widely used in underwear, T-shirts, children’s wear, sportswear, and casual wear, depending upon their diverse characteristics [94].

(3) New materials

Research and development of high-tech materials provide new ideas for the exploration of the sustainability of clothing materials. These novel synthetic materials are often called “supermaterials,” which are highly functional in many ways. And they can be good substitutes for natural substances, thus effectively reducing unnecessary demand from the environment, especially from the perspective of animal protection. Tyvek®, a spun-bonded material made from high-density polyethylene fibers, developed by DuPont™ in the U.S., is a good example.⁹⁶ In the 2003 battle against SARS (i.e., severe acute respiratory syndrome), Tyvek material was used to produce one-off protective isolation clothing, which played an important role in providing reliable protection for white-coated soldiers fighting at the frontline of the battle against the disease [97]. In 2020, Tyvek is again taking a vital part in producing personal protective equipment (PPE) in the fight against COVID-19. Actually, Tyvek is very suitable as a multifunctional material. It has balanced physical characteristics, combining the advantages of paper, cloth, and film; it is not easy to deform, is soft and smooth, light and tough, of excellent opacity, moisture-proof, resistant to water-based stains, and so on [98]. As an excellent application in the fashion industry, famous companies like Bosideng and Xuezhongfei use Tyvek as lining material for down clothes, which not only reduces the vulnerability of down clothes to moisture and mildew, but also improves the touch property of their clothes [99]. And what is especially important is that this “ethical” material protects geese and ducks from being mistreated. PrimaLoft®, a sustainable synthetic microfiber insulator originally developed for the U.S. Army, is also a cruelty-free alternative that is as soft and warm as natural lining material while outperforming goose or duck down in retaining 96% of its insulating ability when wet [100]. KOBA faux fur is another synthetic material made with 100% DuPont™ Sorona® fibers, which is a competitive alternative to real animal fur, which helps to save numerous animals destined for coats, the lining of boots, and other fashion accessories. It is a bio-based high-performance polymer that contains 37% annual renewable plant-based ingredients [101]. It softens its environmental impact while simultaneously offering the benefits of real animal fur and design flexibility, which could be attractive to a fashion industry that is both eco-conscious and socially responsible. Stella McCartney became the first

fashion designer to launch sustainable Koba “fur-free fur” in September 2019 [102].

4.2. Sustainable Design Methods

Innovative research in material and design techniques are two main approaches to realizing advanced design ideas. The latter provides designers with more freedom for creation. Meanwhile, as design techniques determine the final form of a product that more easily resonates with consumers from the perspective of spreading design ideas and encouraging purchase, exploring novel and advanced design methods and techniques is and will be the mainstream way to achieve sustainable fashion from a broad viewpoint.

In the search for sustainable fashion, many design methods have been created and are under continuous development. Most of them are based on two principles: “zero waste” and “recyclable.”

4.2.1. Zero-Waste Design

Zero-waste design, as the name suggests, means using clothing materials as efficiently as possible so as to reduce unnecessary waste during apparel production [103]. Usually, a garment comes into being through the steps of style designing, pattern making, marking, grading, and producing. A designer does not often bother to consider the usage rate of fabric during his fully loaded work, deciding on everything from overall garment style to detailed decorations. Style designing determines pattern making. The latter determines marking, which plays a vital role in saving fabrics. Actually, waste is produced from the starting point, or the design stage. And because designing and marking are two processes that are connected but separate, according to conventional perspectives on designing and producing, waste of materials seems unavoidable, and the marking process is just a measure of remediation. The clothing materials discarded every day in a garment factory could be piled up into a hill.

Nowadays, the inner meaning of design is being re-examined. Influenced by the trend of environmental protection, many designers have begun to explore more simplified design expression. They try to control the use of fabrics from the initial stages of style development by fully considering the shape of each piece of garment and making detailed planning and layout of the fabric. This conceptually and technically makes for higher requirements for contemporary designers. As more and more designers join, the approaches to zero-waste design are being fully developed.

(1) Full utilization of fabric

The most straightforward and original way to the so-called zero-waste garment design is to apply simple skills such as stretching, twisting, winding, or knotting to a whole piece of cloth, or to sew up the pieces of a regularly cut fabric, so as to produce a “one-piece” garment. Some designers get inspiration from classic clothes of ancient times such as the chiton and himation of ancient Greece [104], and the tunic [105], loin

cloth, and bog coat of ancient Egypt [106], to create one-piece garments of various styles [107–109]. The one-piece garment can be of a variety of styles. Nowadays, with the efforts of designers, one-piece garments prevent unnecessary waste of fabrics during cutting, and also satisfy modern consumers’ aesthetic pursuit of diversified and individualized garments.

One-piece garment, as its name implies, is designed and made by fully utilizing a whole piece of fabric. If the concept of sustainability is implanted into the traditional production process of clothing, two design methods, namely, puzzle cutting and the mosaic method, can be developed to realize such a one-piece garment. The puzzle-cutting method requires cutting the fabric into pieces whose shapes are reasonably similar to the original pieces of a garment under the premise that these deformed pieces will use the whole fabric to achieve the full utilization of the fabric. The mosaic method requires that the designer divides fabrics, forms different repetitive or closely related unit pieces, and splices and reorganizes them after cutting. This method aims to minimize the unusable fabric fragments at the edges of fabrics. Compared with puzzle cutting, although it may not necessarily make the 100% utilization of fabrics, it is possible to make a better-looking garment that is spliced by special pieces, which is difficult to complete through puzzle cutting. Designers Issey Miyake, Zandra Rhodes, Elena Ryleeva, David Telfer, Holly Mcquillan, Farrah Floyd, Charlotte Bialas, Malaika, and Yeohlee Teng are outstanding practitioners in developing sustainable and fabulous-looking fashion by applying various techniques to fully utilize clothing materials [110–112].

Besides, innovative designers also try to source their textiles from materials that are abandoned or overflow in the industry. For example, Karen Glass loves to hunt textiles from flea markets, individual clients, and scraps from textile art houses, factory sample rooms, or cutting room end cuts. By stitching bits and pieces together, Glass creates seasonless, high-fashion clothing that can be worn for a lifetime [113]. Similarly, Daniel Silverstein applies an upcycling technique called “re-roll” to reuse the scraps overflowing in the supply chain to create unique and imaginative clothing patterns [114].

(2) DPOL technology

Direct panel on loom (DPOL), invented by Siddhartha Upadhyaya, an Indian designer, omits the cutting process. After computer processing, the cloth can be directly woven into tailoring pieces on a loom. At the same time, the texture and pattern on the surface of the fabric can also be directly woven. It reduces production time and avoids the necessity of cutting, which produces waste during the process [110].

In addition to the above methods, negative tailoring, 3D printing, seam-free knitting, biological fashion, and other technologies are also emerging and getting more and more attention. Besides, some avant-garde brands such as Blessus, Refinity, and Dutchspirit have made new attempts too. They sell garments in pieces instead of as a whole; thus, a consumer can participate vigorously in the creation of fashion by putting different pieces of his (or her) choice together to produce a look that is uniquely of his (or her) style [115].

4.2.2. Recycling Design

Unlike the above-mentioned means, which highly depend on fashion creators' design skills and overall awareness of sustainable fashion during the whole design process, the idea of recycling or reusing might be a simpler and more straightforward way to achieve sustainability in fashion development. One of the difficulties in developing sustainability in fashion industry is that, as trends change rapidly, the rate at which clothing is discarded into waste or potential waste is also accelerating. It is assumed that the "conflict" between fashion and sustainability would be eliminated to a certain extent if the wasted garments could get back into the fashion cycle. In this sense, an effective way to realize sustainability in fashion could be to develop techniques and mechanisms to recycle or reuse the abandoned garments and fabrics so as to reduce the ever-greater amount of fashion waste produced by the industry as it moves forward every single minute. Designers like Alabama Chanin from the U.S. are trying to develop innovative design methods to make original garments and accessories from waste fabrics [116]. Meanwhile, the sharing economy is developing rapidly in fashion industry in recent years. Various web-based second-hand clothing markets such as Ebay, Gumtree, Thred up, and online fashion rental platforms such as Rentez-Vous, MUD jeans, YCloset, Le Tote, etc., have emerged; their core idea is to extend the life span of clothing by repeatedly putting clothes on the market through an appropriate business mode driven by the sharing economy so as to realize sustainability [117–120].

Human beings have realized the need to live in harmony with nature and are making a constant effort to achieve sustainable development. With the great efforts made by our designers, many innovative design ideas have emerged. But whether now or in the future, the development of sustainable fashion will inevitably encounter many difficulties. How to overcome these difficulties is not only a challenge for designers, but also for every link in the sustainable fashion industry chain (from raw material production and processing to marketing).

4.3. Sustainability-Driven Design Management

Since sustainable fashion can hardly be fully realized in a short period, designers need to choose and trade off aspects of the whole production process or product itself for the concept of sustainability. It tests the designer's management ability of the overall design process. Under the guidance of the sustainable concept, designers need to clearly understand the source and footprint of all materials in the design process and manage them well. From the composition and performance to the recyclability of the materials, the principles of fashion sustainability should not be violated as far as possible in the entire design process. Designers of the current era should not only consider the target market's aesthetic and physiological demands, but also be responsible for knowing the materials they use and to manage the design process in an environmentally friendly direction during the expression of their design philosophies. A carbon footprint analysis, also known as a greenhouse gas (GHG) emissions assessment, evaluates the GHG emissions caused by the manufacture of a product or any given activity whose

aim is to identify possible ways to lessen GHG emissions as an important index for sustainability assessment [121]. Carbon footprint analysis has been widely used in sustainability studies (e.g., a joint use of carbon footprint analysis and energy evaluation methods to assess the sustainability of the grain system in China) [122]. Mohammad et al. applied carbon footprint analysis to estimate the current and future trends of water consumption by electricity production sectors for a Turkish energy development plan [123]. Carbon footprint analysis has also been widely used in life cycle assessments in the textile and fashion industries [124]. For example, Karthik et al. used carbon footprint analysis in the sustainability assessment of denim design and manufacturing in India [125]. A product line analysis involving the assessment based on carbon footprint was applied to explore the eco-design of outdoor sportswear [126].

From the point of view of apparel enterprises, retailers need to make similar trade-offs. Recently, some researchers proposed that apparel enterprises could adopt multi-criteria decision-making analysis to manage their supply chain toward more sustainable production and convey the concept to consumers [29]. Hassan et al. proposed using a weighted decision matrix combined with an artificial neural network to carry out sustainability evaluation in product design [127]. Jia et al. developed fuzzy decision matrices to solve the supplier selection problems in fashion business operations with sustainability considerations [128]. A decision-making method based on the technique for order preference by similarity to ideal solutions (TOPSIS) was proposed to assess a fashion company's production performance from the aspect of sustainability [129]. Designers can also use similar methods to manage their own design process by clearly comparing the results after making different choices in each link so as to find the optimal path for a sustainable design.

5. Prospect of Sustainable Fashion Design

5.1. Future Development

In recent years, with the vigorous promotion of sustainable fashion design by designers, many novel creative ideas have emerged and developed, but there are still some shortcomings. At this stage, the immaturity of sustainable fashion design and the difficulty of a sustainable concept to be involved in the whole process from production to marketing are all urgent problems waiting to be solved.

From the design point of view, the main problem is still the difficulty of keeping the balance between sustainability and fashionableness. New materials have high research and development costs, and their performance is to some extent uncontrollable, which sometimes cannot meet the needs of a sustainable design. The current zero-waste design concept requires highly comprehensive skills and techniques of designers. Meanwhile, to use the whole cloth as fully as possible limits to a certain extent the creativity of designers, in which sense fashion is constrained by the concept of sustainable development. Besides, the resources consumed under certain

circumstances during clothing recycling are not less than those consumed in the production of new fabrics, so it is hard to say if it is sustainable in the true sense. In addition, the use of recycled clothing (or fabrics) will inevitably have certain limitations. For example, in most cases, they cannot meet the creative needs of designers. More importantly, there may be potential safety issues in the recycling of waste garments, such as whether the recycled garments have untreatable pollution, whether the recycling process is safe and hygienic, and so on. Last but not least, the lack in transparency of the garment recycling process will also hinder the circulation to a certain degree.

The problem of fashion sustainability does not exist only in the area of design. The development and innovation of the apparel industry need to take into account all links in the supply chain, starting from materials procurement, design concept generation, production, delivery, to sales, after-sales, etc. How can apparel companies update their production and management models to match with the development needs of sustainable fashion? How can existing marketing strategies keep up with the sustainable-fashion-driven marketing concepts? These are the practical problems that the fashion industry has to face on its way to sustainability. In addition, as sustainable fashion becomes more and more popular, some fashion brands take the concept of sustainability as a means of profit. Some brands choose to exaggerate the subtle adjustments of the products in their publicity, but in actuality, they hide the genes of fast fashion under the appearance of sustainability. Some other brands, in order to achieve so-called sustainability, emphasize the adoption of costly materials and hand-making processes in product development, making the product too expensive to access, and becoming an “ecoluxury,” or ecological luxury, which is a distortion of the actual concept of sustainability.

In the future, there will be the challenges of how to use advanced technology, how to implement new design concepts to fundamentally reduce waste, how to make the concept of sustainability ingrained in the heart of the public, how to let sustainable fashion become a habit, how to make sustainable concepts and technology well implemented in the whole process of garment production, logistics, marketing, etc. These are issues that need to be solved by the joint efforts of entrepreneurs, designers, consumers, and even the whole society.

5.2. Regeneration Design of Garment Structure

Nevertheless, as the central link of sustainable fashion, the innovation of design ideas will be the premise and top priority for the sustainable development of the fashion industry.

Regenerative design is a relatively new concept in the field of sustainable fashion design [130]. The so-called regeneration can be understood as “contrary to the one-off” or “reuse of already used items.” For clothing, when the fashion color and style change, consumers need to buy new clothes to cater to ongoing fashion trends. But in fact, outdated clothes may not be greatly depleted when they are abandoned. At the same time, due to the cyclical nature of fashion, under the guidance

of future fashion trends, consumers may repurchase products that are very similar to once-discarded clothing, which results in a waste of resources. “Structural renewable clothing” lets consumers buy only the necessary “parts” during the replacement of fashion trends, reduces the space needed for clothing storage, and reduces the waste rate, so as to achieve fashion sustainability.

Different from the conventional understanding of sustainable fashion design, the essence of the structurally renewable garment is that through special design, all parts of the garment can be effectively combined and spliced to achieve fragmentation of the garment so that garment parts can be replaceable or reshaped, thereby prolonging the service life of apparel products. This type of design can make clothes more changeable, such as changing with the growth of the human body, changing with the seasons, and changing with fashion trends, so as to actively extend the life of clothes. In this way, “one piece of clothing” can meet the needs of different body frames and wearing occasions so as to achieve sustainability.

If the fragmentation and reorganization of clothing can be truly achieved, fashion design will no longer be unilaterally dominated by designers. Consumers will also be able to participate in design. The variety of changes and recycling of clothing parts can make the clothing more diversified and personalized while achieving sustainability. “Customized clothing” would become something no longer available to ordinary people. Everyone can have their own unique and changeable clothing. In addition, the fragmented design can give full play to the designer’s imagination. Through the design of the clothing components, the designers will be able to break the limitations set by the sustainable concept, so as to create beautiful, diverse designs.

At present, although there is no design that can completely turn clothing into components so that all parts of a garment can be completely disassembled and replaced, similar ideas are being realized, such as clothing whose patterns can be changed to a certain extent (for example, clothing that can change between skirts and pants [131] or clothing that can be simply disassembled [132]. Research on “renewable structure” has begun. How to unitize and fragment a garment to the largest extent so as to make it a real “transformer” will be a very interesting and promising direction for sustainable fashion design in the future.

5.3. Hybrid Zero-Waste Design

Hybrid zero-waste design is a design method derived from classical zero-waste design practices. It combines traditional zero-waste design with DPOL technology to reduce or eliminate waste in production and develop new expressions at the same time. In this case, the intersection point is fashion design and textile design. A simultaneous design approach is adopted to connect fashion and textile design [133]. This design approach involves not only the design object or form, but also the hybrid practicing methodologies; thus, it entails relatively higher requirements for weaving technology.

McQuillan [134] experimented with hybrid zero-waste design methodology, according to which, with the help of 3D modeling software (i.e., Clo3D), a garment (e.g., a T-shirt) was designed in 3D form and then translated into weavable 2D structure, and finally be once again made 3D. During the process, the digitized fabrics were made multilayered and went through three iterations, stacking, sliding and expanding, respectively, to finally become a zero-waste garment which, it was claimed, produced only a small amount of yarn waste in the auxiliary selvage on cut pieces. And according to this zero-waste method, the size of the design could be easily graded to fit different body dimensions. The hybrid zero-waste design approach makes it possible to design the textile structure and the garment/3D form at the same time, which points to an innovative and highly efficient way to achieve sustainable fashion design. As a future design methodology, hybrid zero-waste design provides possibilities for designers, manufacturers, and possibly consumers in the years to come.

6. Conclusions

Today, sustainable development has become the wind vane of the fashion industry. As the central link in the fashion industry chain, design plays a relatively important role in realizing the sustainable development of fashion at its root. Starting from the introduction of the concept and historical development of sustainable fashion, this paper first summarized the current status of sustainable fashion design. Then, from the perspective of clothing design and development, the paper introduced sustainable fashion design at the present stage, including the use of environmentally friendly materials and various popular design techniques, methods, and concepts. On this basis, the development trend of sustainable fashion design in the future was put forward as well as some emerging innovative design means.

As Yelavich et al. pointed out in their work "Design as future-making," design cannot act in isolation from the complex social, economic, and environmental issues that envelop it [135]. Designers shoulder important social responsibilities in the process of sustainable fashion development. Future designers should be cultivated to strengthen their deep sense of identity with sustainable fashion. They should learn to think from the perspective of sustainable fashion design management, boldly try new design methods, make efforts to integrate the sustainable concept with fashion aesthetics, and with the cooperation of all links in the industry chain, to imperceptibly guide rational consumption and lead the market in a sustainable direction.

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