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ZERO WASTE APPROACH IN SUSTAINABLE FASHION DESIGN: DESIGNER PERSPECTIVE FOR PRE-CONSUMER WASTE MANAGEMENT

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ABSTRACT: In recent years, the climate crisis that humanity has faced has increased the importance of sustainability discussions, bringing the issue of waste reduction and solutions in textiles and ready-to-wear to the forefront. In the fashion sector, many designers, engineers, and brands, both from within and outside the industry, are developing methods to reduce waste at pre-consumer and/or post-consumer stages. These efforts aim to adopt various innovative approaches for sustainable fashion and environmentally friendly production. Reducing waste generation is a crucial step in minimizing the environmental impact of the clothing industry. Within the scope of this study, existing knowledge on zero-waste fashion design has been compiled and analyzed using the literature review method. Research in this area contributes to the wider adoption of sustainable practices within the fashion sector. Zero-waste fashion design is one of the significant approaches promoting sustainability in the 21st-century fashion industry. This approach prioritizes the prevention of pre-consumer waste generation. Consequently, it emphasizes pattern-based design and the development of methods that minimize waste during the production processes of garments. In the production of designed garments, efforts are made to either generate no waste or minimize textile waste (low waste) as much as possible. For zero-waste fashion design, designers develop various design solutions and methods focused on preventing waste generation during the transformation of the design into the product. These solutions include pattern design ideas such as jigsaw and tesselation, fabric manipulation, and minimal cutting approaches. Additionally, these solutions are diversified by integrating technologies such as 3D modeling and digital prototyping that optimize design processes. This study aims to examine design approaches developed for pre-consumer zero-waste fashion design and present alternative production methods to the traditional fashion industry. In this context, the study aims to contribute to the literature by compiling innovative approaches that take into account pattern-making, material selection, technology, and interdisciplinary perspectives in sustainable fashion design. Considering the ongoing research and studies on zero waste, the guiding nature of this study becomes increasingly significant.

Keywords: Zero waste in textile, zero waste pattern, sustainable fashion

SÜRDÜRÜLEBİLİR MODA TASARIMINDA SIFIR ATIK YAKLAŞIM: TÜKETİCİ ÖNCESİ ATIK YÖNETİMİ İÇİN TASARIMCI BAKIŞ AÇISI

ÖZ: Son yıllarda insanlığın yüz yüze geldiği iklim krizi sürdürülebilirlik tartışmalarının önemini arttırırken, tekstil ve hazır giyimde atık miktarını azaltma ve çözüm yolları üzerine tartışmalar önem kazanmıştır. Moda sektöründe, sektör içi ve/veya dışından birçok tasarımcı, mühendis ve marka, tüketici öncesi ve/veya sonrası aşamalarda atık miktarını azaltmaya yönelik metotlar geliştirmektedir. Bu çabalar, sürdürülebilir moda ve çevre dostu üretim için çeşitli inovatif yaklaşımların benimsenmesini amaçlamaktadır. Atık oluşumunun azaltılması, giyim sektöründeki çevresel etkilerin en aza indirgenmesi için önemli bir adımdır. Bu çalışma kapsamında, sıfır atık moda tasarımı konusundaki mevcut bilgi birikimi, literatür taraması yöntemi ile derlenmiş ve analiz edilmiştir. Bu alanda yapılan çalışmalar, moda endüstrisinde sürdürülebilir uygulamaların daha da yaygınlaşmasına katkıda bulunmaktadır. Sıfır atık moda tasarımı, 21. yy moda endüstrisinde sürdürülebilirliği teşvik etmeye yönelik önemli yaklaşımlardan biridir. Bu yaklaşımda öncelik, tüketici öncesi atık oluşumunu engellemektir. Bu durum ise, tasarımda kalıp odaklı çalışmayı ve giysi tasarımlarının üretim süreçlerinde, atık oluşumunu minimize etmeyi hedefleyen metotlar geliştirilmesini öncelikli kılmaktadır. Tasarlanan giysilerin üretiminde, hiç atık bırakılmamasına veya tekstil atığının mümkün olduğunca minimize edilmesine çalışılmaktadır. Sıfır atık moda tasarımı için, tasarımın ürüne dönüşmesinde, tasarımcılar tarafından atık oluşumunu önlemeye odaklı çeşitli tasarım çözümleri ve yöntemler geliştirilmektedir. Bu çözümler arasında yapboz, mozaik gibi kalıp tasarım fikirleri, kumaş manipülasyonu, minimal kesim gibi yaklaşımlar geliştirilmekte; 3B modelleme ve dijital prototipleme gibi tasarım süreçlerini optimize eden teknolojilerle birlikte bu çözümler çeşitlendirilmektedir. Bu çalışma ile sıfır atık moda tasarımında tüketici öncesi sıfır atık yaklaşımına yönelik geliştirilen tasarım yaklaşımlarının incelenmesi ve geleneksel moda endüstrisine alternatif üretim yöntemlerinin sunulması amaçlanmaktadır. Bu kapsamda çalışmada, sürdürülebilir moda tasarımında kalıp, malzeme seçimi, teknoloji ve disiplinlerarası yaklaşımı gözeten inovatif yaklaşımlar derlenerek literatüre katkı sağlanması amaçlanmaktadır.

Anahtar Kelimeler: Tekstilde sıfır atık, Desende sıfır atık, sürdürülebilir moda

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1. INTRODUCTION

The climate crisis, which was noticed toward the end of the twentieth century and which humanity has inevitably faced in recent years, has enabled the questioning of consumption habits, which is a sociocultural problem besides the pollution in the environment.

Textile industry has destructive effects in terms of ecological, ethical, and social aspects. This effect has increased exponentially, especially with the fast fashion trend that emerged as a sales strategy in the 1980s. The main purpose of this trend is to encourage the purchase of new fashionable clothes by providing cheap clothes to consumers and ensuring that consumers follow the fashion trends. Fast fashion brands have accelerated their production processes in this direction and aim to offer low-cost products by mass production. Such brands, following new fashion trends, frequently develop new collections and offer new options to consumers by producing low-cost clothing not only in the textile field but also in food and agriculture, construction, furniture, automotive industries. Fast fashion, with its low prices and fast fashion cycle, caused a different production and consumption culture structure by gaining popularity among consumers.

The phenomenon of fashion is one of the main architects of consumption culture, while affecting the psychological satisfaction of consumers by triggering the desire for change beyond their physical needs. Changing silhouettes, models, fabrics, and patterns in apparel fashion are designed and marketed with a new identity package and story. Fast fashion, with its business model that shortened the design–production– sales cycle since the 1980s, has triggered consumption and created a constant desire to buy [1]. Today, although a sustainable fashion trend is on the agenda, discussions on reducing the amount of waste in textile and apparel which are among the reasons of the climate crisis, have gained importance. In solving the waste issue, one of the problems of the 20th and 21st centuries, it has been inspiring with observation from nature that the output of one cycle is the input of another cycle. The waste management strategy, which was expressed as a concept in the 1970s and described as "zero waste", emerged with the effect of the return to natural processes and the understanding of circular economy. It is possible to come across a cycle parallel to the basic logic of the waste management strategy in the 19th-century [2].

The main reason why waste generation was not a cause for concern until the 19th-century is related to production and consumption practices. In these periods, food scraps were used as animal feed, end-of-life items were turned into child's play, broken items were repaired instead of thrown away, durable items such as furniture, watches, and wristwatches were handed down from generation to generation, organic fertilization was made in agriculture and livestock finds a new purpose, the ashes were used to control pests and fertilize the soil. It is seen that circular economy model dominated and very little waste was produced until the nineteenth century, there was no ecological concern. It is not possible to talk about a society or culture without waste in history. However, for humans, waste was rarely a concern before the industrial age. This cycle has changed with urbanization, increasing population, and, more importantly, technologies that make cheap mass production items accessible worldwide [3].

The excess of easy-to-use, disposable products and the formation of consumption societies in which the use-and-throw away consciousness is established has accelerated the generation and amount of "waste". While the Industrial Revolution increased production and urbanization by facilitating access to raw materials and processing, the wrong policies that followed have created consumption societies with passive participation in production instead of actively participating in production. The concept of sustainability, which has taken its place on the international stage since the 1990s, is defined as an environmental, social, and economic development model. The basis of sustainability lies in the correct and fair use of resources in a way that can be transferred to future generations, the least damage to the environment, the ability of the entire existing human population to reach decent living standards and sustain their lives [1].

Environmental (atmosphere, soil, oceans-sea-coasts, water, biodiversity), economic (economic structure, consumption and production patterns), social (equality, health, education), housing, security, population) and institutional (institutional environment, institutional capacity) indicators were determined. With all these indicators and sub-themes, an integrative approach has being emphasized on what the principles of a sustainable society should be and which actions should be taken to achieve sustainability goals.

These principles address within the framework of integrative policies respecting life, increasing the quality of life, protecting the diversity of life on earth, minimizing the consumption of non-renewable resources, not exceeding the carrying capacity of the earth, changing habits, allowing everyone to protect their own region, development and the environment [4].

Material selection, design and production processes, quality and durability, reuse and recycling, fair trade and social responsibility, and conscious consumption are the important topics discussed in the textile sector [5,6,7] In addition, among the topics on the agenda are how to create a circular economy with inter-sectoral waste management and how to establish a sustainable relationship, ensuring scraps from a sector to be used as raw material input for another sector. For this purpose, industrial symbiosis and circular economy studies have been conducted to prevent waste generation through collaborations with different sectors, such as the use of non-consumption fish skins in the textile sector, rather than waste in the food sector [8].

Figure 1. Circular Economy Package [9].

The EU's circular economy action plan focuses on a future-oriented agenda for a cleaner and more competitive Europe, together with economic actors, consumers, citizens, and civil society organizations. Within the scope of this action plan, targets for different sectors have been determined. Targets for the textile industry include developing eco-design measures, ensuring the purchase of secondary raw materials, combating hazardous chemicals, and increasing the collection, classification, reuse, repair, and recycling of textile wastes at high levels [9].

The implementation of a sustainable production model and the creation of awareness on both consumer and producer bases involve complex processes. Effective management of these processes and adoption of the principle of sustainability are important for reducing environmental and social impacts of the fashion industry. Production with a sustainable understanding starts with the preference for sustainable and recyclable materials. It is important to use environmentally friendly techniques and technologies during the production phase. Again, during the production phase, it is aimed to adopt practices in line with the sustainability principle, such as minimizing waste generation, saving energy and water, and keeping the use of chemicals under control. It is necessary to use environmentally friendly materials for labeling and packaging processes and to prefer approaches such as minimal packaging. In fashion industry, to promote the long-term use of the clothings after reaching the end user, designing durable and quality products, repairability, and reusability should be considered. It is necessary to create consumer awareness in normalizing the use of sustainable clothing, such as making repairs, upcycling, and recycling practice routines in post-purchase maintenance and disposal processes. In other words, even when the lifecycle of the clothes is completed, a sustainable disposal method should be preferred and recycling possibilities should be evaluated. The implementation of these processes with awareness and cooperation among all stakeholders is critical for spreading sustainability awareness.

Brown adressed how sustainability is integrated into business strategies in the field of textiles and fashion in her book Eco Fashion, which includes environmentally friendly and socially conscious designers and brands [10]. These strategies include methods such as reduce, reuse, recycle, and in addition to these 3Rs, rebuy, upcycle, and repair, which aim to reduce the amount of waste generated before and/or after consumption (Figure 2).

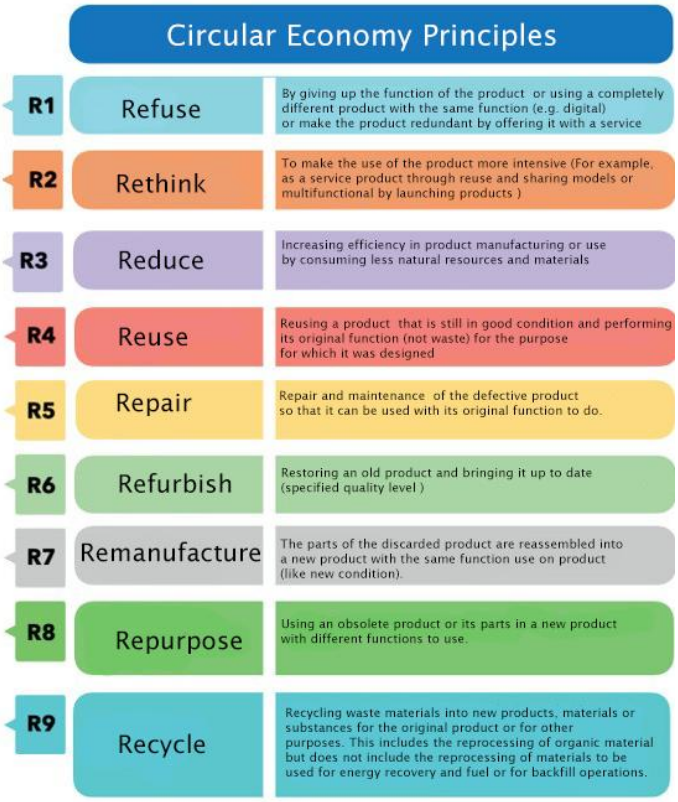

Figure 2. Circular Economy principles [9].

It is possible to save energy, resources, time, and even cost with a versatile design. Approximately 80% of the environmental impacts of the product can be estimated at the design stage [11]

Studies on sustainable fashion design have shown a significant increase in the global literature. When these studies are considered chronologically, the effects of the concept of sustainability on the fashion industry can be understood more clearly.

In the second half of the 20th century, sustainability has become a hot topic in fashion, as it has in many other areas. It has been discussed in depth in the book *Sustainable Fashion and Textiles: Design Journeys* by Fletcher (2008) [12]. Fletcher has done a pioneering study on the integration of sustainability into fashion design and discussed how sustainability principles can be applied to the fashion industry. Gwilt and Rissanen (2011) examined the methods and strategies needed to shape sustainability in fashion design in their work *Shaping Sustainable Fashion: Changing the Way We Make and Use Clothes*[13]. This study explored ways to create a more sustainable fashion industry by addressing issues such as waste reduction and resource efficiency in the design process. Gardetti and Torres (2013) provide a broad perspective on how sustainability values can be applied in design, production and consumption processes in their book *Sustainability in Fashion and Textiles: Values, Design, Production and Consumption* [14]. In 2015, Niinimäki (2015) highlighted how ethical fashion plays a

role in sustainable fashion design in his study titled *Ethical Foundation in Sustainable Fashion* [15]. This study examined the relationship between consumer behavior and ethical design. *Sustainable Fashion: A Cradle to Upcycle Approach*, published by Henninger et al. (2017), addressed the issues of circular economy and sustainable fashion design [16]. This study emphasizes waste management and reuse strategies for sustainability in fashion. In addition to these studies; studies in Turkey that address sustainability through the fashion sector offer a broad perspective on this field. Yıldırım (2017) focused on second-hand clothing and waste reduction techniques within the framework of recycling, upcycling and reuse [17]. Kipöz and Atalay (2015) addressed fashion within an ethical framework. In her book, *Modada Yavaşlık* (Slowness in Fashion) [18], published in 2021, Şölen Kipöz evaluated sustainability in terms of design, craft, local production and economic production model; she expanded her work on this subject with her book, *Sürdürülebilir Moda* (Sustainable Fashion) [19], published in 2021. Bursalıgil (2019) examines zero-waste methods in clothing design, investigating their impact on environmental sustainability [20]. Çırakoğlu (2019), on the other hand, focuses on the role of circular economy and sharing-oriented consumption models in clothing design [21]. While Bursalıgil emphasizes the integration of zero-waste methods into design processes, Çırakoğlu focuses on how sharing economy can support sustainability. Odabaşı and Şahin (2019) examined how this approach can be integrated into educational processes by addressing sustainable design in an educational dimension [22]. In addition, Nesrin Türkmen (2009) emphasizes the significant role of designers in driving sustainability [23]. She argues that designers should adopt ecological literacy and purpose-driven design principles, focusing on efficient resource use, optimizing production processes, and encouraging consumers to engage in conscious consumption. By positioning designers as change agents in building a sustainable future, she highlights the importance of interdisciplinary approaches and innovative technologies in strengthening this role. Şahin and Odabaşı's study, *A Literature Review on the Role of Fashion Designers in Sustainable Development*,"examines how fashion designers can contribute to sustainable development goals [24]. The work focuses on how designers can integrate sustainability principles into design processes to reduce environmental impact, and the role of educational processes in increasing sustainability awareness. It highlights the potential for designers to create more environmentally friendly production processes by developing sustainability consciousness. Enes and Sayğılı (2023) drew attention to the life cycle of textile products with her study on circular fashion design strategies [25].

This research focuses on zero-waste clothing design approaches to reduce the amount of pre-consumer waste in fashion design.

2. METHOD

In this study, a review on pre-consumer zero-waste fashion design was conducted using the literature review method. Although the purpose of a literature review is briefly defined as obtaining the necessary information on the research topic, Bouner (1996) emphasizes the following aspects of a literature review: "Identifying methods that may be relevant to the research, determining pioneering and groundbreaking works in the field of research, and analyzing opposing viewpoints" [26]. Using this method, various sources such as articles, papers, books, reports, theses, interviews, and videos on the subject of pre-consumer zero-waste fashion design were reviewed. Following a comprehensive analysis of the reviewed sources, a compilation study was conducted based on the existing literature. Considering that ongoing studies and research on zero-waste design continue to emerge, this study's guiding nature gains importance. In line with the aim of the study, publications on zero-waste fashion design were examined in detail, explanations were provided on the topic, leading designers and their methods were identified, and the applicability and potential impacts of the pre-consumer zero-waste design process in the fashion industry were discussed.

3. PRE-CONSUMER WASTE MANAGEMENT AND DESIGNER ROLE IN TEXTILE AND FASHION DESIGN

Kipöz and Atalay (2015) state that the relationship between the designer, producer, and consumer exhibits a linear and hierarchical structure, where the designer and producer play a manipulative role over the consumer. Referring to the analogy by design theorist Clive Dilnot (2009), the designer is positioned as a "servant" serving the market economy, while the consumer is positioned as a customer. Additionally, based on Bourdieu's perspectives, it is emphasized that in order for fashion to become a form of cultural capital, the media actor must also be included in this structure. In this context, mainstream fashion media is noted for creating a consumption-driven narrative to present the designer and their production as economic value. This production-consumption relationship in global fashion is defined as a process that, as described by Manzini (1995), is based on "making to produce" and results in "waste" [27].

The fashion industry consists of four fundamental layers. The first layer includes raw material suppliers such as factories and yarn producers. In the second layer are designers, manufacturers, wholesalers, and vendors. The third layer is the retail layer, which comprises stores and sales distribution points. Finally, the fourth layer includes supportive services such as the press, advertising, research agencies, and fashion forecasters, which help connect the other layers and facilitate the delivery of goods to the end consumer. This structure reflects a traditional understanding of the infrastructure of fashion [28]. When each layer is not properly managed, it can influence and trigger pollution and waste issues in an interconnected manner.

The waste generated by the production and consumption of clothes, especially textiles, is generally handled in two categories. These are pre-consumer (production) waste produced by textile manufacturers post-consumer waste generated by public. Clothing and other textiles that are consistently promoted to overconsumption have increased the volume of both pre-consumer and post-consumer textile waste [29].

Along with the dramatic increase in production due to fast fashion phenomenon, there has also been an increase in textile waste both before and after production. Studies have shown that there is a significant amount of waste in the fabric used in the production phase; and in 2012, 60% of the approximately 150 million garments produced globally were thrown away after just a few years of production [30].

Pre-consumer wastes in terms of the product life cycle perspective include all materials that are consumed during clothing production and are not part of the composition of the product [29]. Fabric residues in cutting processes, yarn residues in sewing processes, and chemical wastes in dyeing processes are released. Recovery of pre-consumer waste is a textile waste management strategy in textile and fashion design. An estimated 400 billion m^2 of textiles are produced annually, and unfortunately, because of the traditional clothing design process, approximately 15% of the fabric remains on the cutting table [31]. Dobiliate and others have come up with the research conducted on three enterprises to determine the amount of pre-consumer waste in Lithuania, it was determined that the total amount of material used for the production of die-cutting wastes can reach approximately 25% depending on the product variety [29].

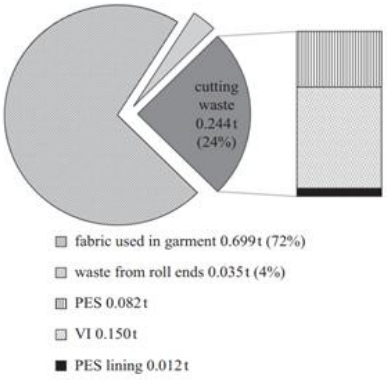

Figure 3. Distribution chart of all materials and cutting waste used in a business that produces casual blouses and dresses with the traditional method [29].

With this feature, the traditional clothing design method in the clothing production process is the area with the highest amount of fabric waste. The traditional clothing design process starts with the drawing, and for the designed drawing to take its three-dimensional shape, it must first be analyzed and reduced to two dimensions with the pattern making. At this point, it is of great importance that the removed parts are effectively placed on the fabric. It is desirable that the least amount of fabric waste is generated. However, in the traditional pattern making process, the focus is entirely on design, so the waste generated during pattern placement is not considered appreciably [31,32].

During the production phase, designers can greatly affect the amount of waste through the material choices, pattern placement techniques, and cutting techniques they use during the product development process. In this context, pre-consumer zero waste fashion design approaches have been developed by designers who aim to resolve waste generation at the production stage.

4. ZERO WASTE DESIGN STRATEGIES IN FASHION DESIGN

From past to present, we can observe that 'zero waste' approaches in clothing production have been familiar. Today, while the concept of design has an industrial aspect, progress is also made with certain references drawn from history. In addition, the zero-waste approach has evolved due to various cultural, economic, and technological reasons throughout different periods. Clothing created by stitching pieces of leather together with plant fibers or by developing tying techniques in the early days of humanity to meet the need for protection can be considered the first examples of zero-waste garment design. However, more advanced civilizations such as Ancient Egypt, Ancient Greece, and Rome transformed fabrics into garments using relatively developed clothing techniques, with little to no waste [33].

Greek and Roman garments were shaped using the materials and fabric production methods in hand. Most clothing items used in this period were made of woven fabric that emerged by labor-intensive processes [34]. The woven fabric was too valuable to be wasted by cutting and sewing to fit the body. For this reason, both the Greeks and Romans wore loose-fitting and body-covering garments fastened by folding, wrapping, pinning, draping fabrics, and very rarely by sewing around the body [34].

In traditional clothing, draping techniques and seamless pattern applications, where fabric is wrapped around the body, have been the foundation of garment for centuries across the world. These methods, which do not produce pre-consumer waste, serve as a reference for modern zero-waste garment production. This approach is still used in many countries and cultures today, either as part of everyday clothing or, at the very least, in ceremonial attire. The complex draping methods found in regions such as Asia and Africa (e.g., among the Turkana and Rendile tribes) are particularly noteworthy. It is also possible to see these draping techniques in 20th and 21st-century fashion, especially in beachwear, where single-piece, seamless fabrics are used [33].

21st century pre-consumer zero waste fashion design examples, which is one of the pre-consumer zero-waste fashion design model, can be associated with the Latin American poncho or the Far East traditional costume kimono in its simplest form. However, their application purposes are different. The difficulties of pre-industrial fabric production and the limitations such as the time spent during its production created a driving force for the use of the already precious fabric. In the twenty-first century, environmental awareness and the need of controlling the increasing amount of waste obliged the development of cutting techniques and the creation of new patterns with the help of different techniques and technologies.

Although the traditional Japanese clothing kimono consists of rectangular cuts and is produced for a different purpose than today's sustainability approach, it is one of the inspiring examples that complies with the zero waste fashion concept with the way the fabric is used. People used, transformed and rented the kimono, which was made of precious silk and revealed the identity

of the wearer in terms of style, motif, fabric, technique and color, until it became old [35].

Figure 4. Muromachi Kimono (1336–1573), Met Museum, New York [35].

From 'TUTA', which was designed in 1919, there has been many clothing design studies related to zero waste, which were put forward with technology-based applications in the twentytwenties.

The clothing design called 'TUTA', designed by Italian futurist Thayahtand/Ernesto Michahelies in 1919, is an example of the zero waste clothing design of the 1900s. The design emphasizes simple elegance [36], consisting of a single rectangular fabric with cotton, all pattern components are completed with seven buttons and a belt. In addition to being an example of zero waste pattern design, this design is obviously intended to bring people to "do it yourself" behavior, as all its technical details have been published in magazines. In the “TUTA” example, it is seen that many principles of sustainability such as a waste-free life, a productive society, and zero waste are touched upon.

Many brands and designers develop the zero waste fashion (clothing) approach in their own perspectives and present it in different ways. McQuillan et al. criticize the understanding that the preparation phase is a process independent of design. Drawing attention to the distance between the designer and the fashion producer, both philosophically and physically, it is emphasized that there should be no distinction between the design-pattern-production phases that encompass clothing production [38].

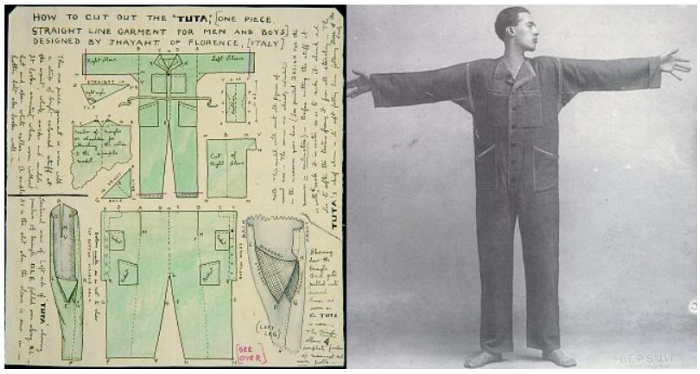

Figure 5. Unisex Thayaht suit with T shape by Ernesto Michhahelies [36].

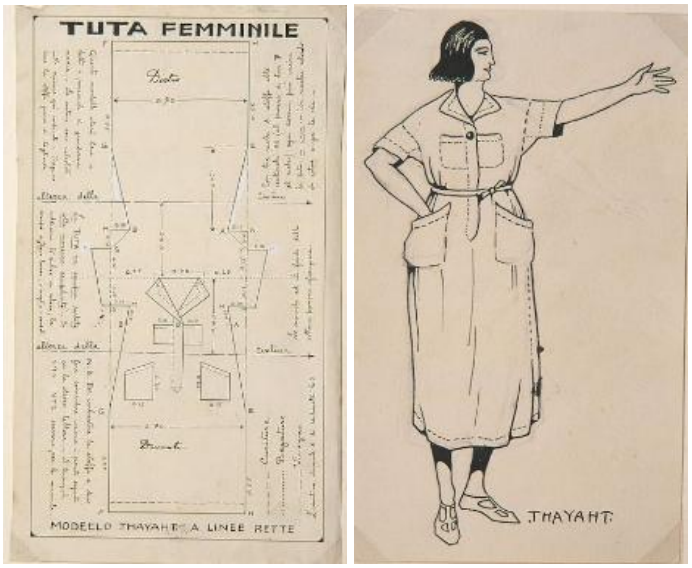

Figure 6. Ernesto Michahelles design T shape and women's clothing design developed from Thayaht suit [37].

Pre-consumer zero waste fashion design includes design approaches for fabric efficiency based on sustainability principles against traditional pattern methods in garment production, an experimental application in the pattern making process, a design based on re-patterning, and designs for the potential of a product to be transformed into different designs. In this application area, geometry is a frequently used method in order to achieve perfect harmony. However, in addition to geometry, 3D modeling opportunities offered by CAD CAM software allow the development of different methods as well as optimizing design processes such as digital prototyping. Tessellation (mosaic tiling), Jigsaw, Embedded Jigsaw, Multiple Cloth Approach [39], Minimal Cutting [40] methods are grouped as zero-waste fashion design approaches [41]. While the combined use of different methods is possible, pre-consumer zero-waste fashion design is an ever-evolving field with experimental applications such as Smart Fashion Production [42], which continuously transforms sustainable fashion. A growing number of designers and companies are contributing to zero-waste sustainable fashion design. According to the research, pre-consumer zero-waste fashion design methods have been evaluated under four main categories from a different perspective. This classification helps

identify which strategies the design methods focus on in line with the zero-waste goal. Additionally, the practices grouped under each category demonstrate how these features are implemented. Moreover, the holistic nature of sustainable design suggests that, while design strategies are categorized based on their focal points, inclusivity among them is always present.

4.1. Pattern and Cutting Techniques:

Pattern placement and cutting techniques aim to solve the waste problem directly at the design stage of the garment form in order to ensure efficient use of the fabric. The designs that are the subject of the study in this context are called zero waste pattern design. The examples given; The focus point in the design process is to optimize the pattern design, placement and cutting techniques in a way that prevents fabric waste. In this context, the cutting techniques, sewing or binding methods used play an important role in foreseeing how the patterns for the designs are placed on the fabric.

Jigsaw Puzzle and the Embedded Jigsaw Method; It is a clothing design method in which pieces of fabric are interlocked. This method aims to make patterns of the design on a two-dimensional plane/fabric almost like puzzle pieces and to make them three-dimensional by cutting from the fabric without wasting the fabric. Both jigsaw and embedded jigsaw methods allow for designers to use varied pattern shapes, much like traditional pattern design. To achieve zero waste, however, the pattern shapes within jigsaw are manipulated to interlock with each other and share cut edges. [40].

Pattern pieces with known width and length are placed on the fabric. In this method, the way one pattern piece is cut complements the way the other pattern piece is cut. When the pieces are completely cut, there is no waste, and sewing is done directly. Designers such as Timo Rissanen, Holly McQuillan, and Mark Liu use this method and contribute to its development. Timo Rissanen (2012), who has a doctorate in practice-based zero-waste fashion design, has defined zero-waste clothing design in particular: fashion history is almost always known as a history of waste. However, we are currently at a turning point in the fashion world in terms of reducing waste, and fashion design is trying to move away from what seems inseparable from waste. While fashion has historically been a wasteful activity, it now deserves admirable recognition because it plays an important role in minimizing waste [43].

Zero-waste clothing designer Mark Liu combines the jigsaw puzzle method with laser cutting applications to produce women's clothing collections. Describing his creative process, Liu says, "I see the vision of what I want and usually have the silhouette in my head. Then I imagine building the dress, visualizing the inside out while moving flat pattern pieces around. The trick is to design in 3D while also visualizing the 2D flat pattern. It is like sculpting while playing Tetris at the same time." [10]. Inspired by the research and books of Michio Kaku, who works in the field of physics, Liu applied modern mathematics to traditional fashion pattern making to develop completely new fashion areas such as "Non-Euclidean Patternmaking" [45].

Figure 7. Timo Rissanen's design, prepared with the Jigsaw Puzzle method [44].

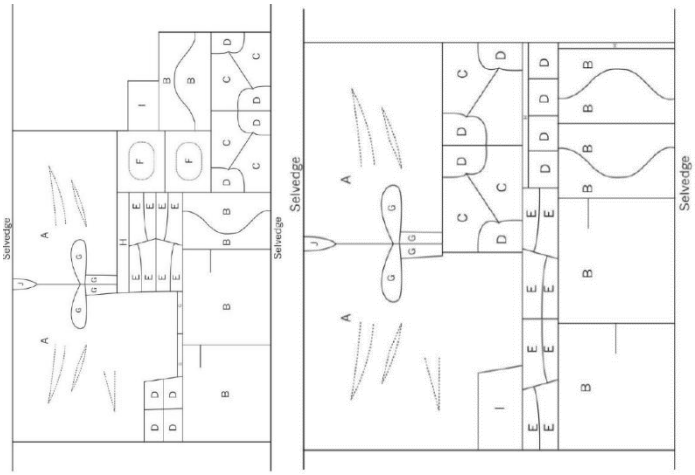

Figure 8. Shirt design made with traditional method and Jigsaw Puzzle method [38].

Mark Liu's approaches in this process are based on both scientific and artistic foundations. Figure 9 illustrates different geometric forms and how these forms are adapted to curved surfaces. The curved regions of the body possess distinct mathematical rules and geometric properties. While applying these forms to fashion design, Liu utilized laser cutting and digital printing techniques to develop a zero-waste production method.

He took a scientific approach, applying to Couture the jigsaw production procedure that would make him a recognized pioneer in the sustainable fashion movement. In this way, it opened a window on how couture pieces in sculptural form can be created. Liu's work offers new perspectives on how mathematical methods and scientific approaches can be applied in fashion design [46].

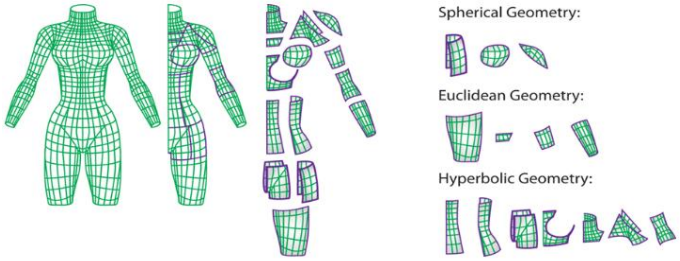

Figure 9. Parts of the body have different curvatures which have different geometric properties and mathematical rules [45].

Figure 10. Eco-conscious and eco-responsible fashion designer Mark Liu's innovative "Zero Waste" fashion collection [10].

The method of tessellation, which can be defined as the separation of a whole piece of certain dimensions into miniature pieces with interconnected edges, without leaving any gaps between them, has been used in the development of different pattern methods. Contrary to jigsaw methods, all pattern shapes are the same in the mosaic method. Designer Holly McQuillan, who used and developed this method, has worked on the fact that the mosaic method gives a perfect result on a fabric that does not have straight edges. Looking for ways to reduce waste on uneven edges, McQuillan used mathematical objects called fractals and hyperbolics [39]. Inspired by the works of Escher, the pioneer of hyperbolic applications in art, "Lizard hyperbolism", he went to reduce the size of the mosaic pieces toward the edges of the fabric. Thus, it offers a way to produce designs with less fabric waste.

Figure 11. Liu's “Zero Waste” fashion collection combines traditional print design and tailoring techniques with laser cutting techniques and digital printing [47].

Figure 12. Circle Limit I [48]

Figure 13. Holly McQuillan clothing pattern design study with reduced edge waste [49, 39, 50].

Minimal Cut; Designs that will be created in a way that minimizes fabric waste, and taking the time and energy spent for sewing to optimal levels are among the new generation design approaches. This may require special cutting techniques and modifications in accordance with the low-waste principle. Fabric waste can be avoided by optimizing the sizes and shapes of the patterns used. From this viewpoint, designers such as David Telfer and Karin Vlug were interested in the method of creating designs with limited cuts on a piece of fabric. Compared with jigsaw or tessellation methods, there is no need to completely cut off the fabric surface. For this reason, there is no need for too many stitching and joining processes; rather, the clothing takes a three-dimensional form by using the binding methods.

Karin Vlug has integrated zero waste practices into her fashion designs during the education process. The graduation collection "One square fits all" is based on fabrics that are shaped only at 90° angles, such as squares and T-shapes. The collection consists of fabrics with tunnels and cutouts that do not require sewing. By making cuts on the fabric and creating tunnels, three-dimensional clothings were created without the need for sewing. The creation of a clothing is possible by tying it together with a ribbon. Vlug states that creating couture without sewing is a new, accessible, and made-to-measure bespoke tailoring vision. Apart from silk and cashmere, Vlug emphasizes the use of generally non-luxury materials such as various types of synthetic fabric. He states that these materials offer endless possibilities because of their soluble structures. He mentions that applying heat to these materials to fuze them into a new substance serves as an alternative method for creating tunnels and incisions [51].

David Telfer, who develops simple patterns and minimal-seam designs, collaborated with the North Face brand as part of the Textiles & Environment project to create a jacket design based on the zero-waste design model principle. This collaboration demonstrated increased fabric efficiency compared with traditional methods. However, despite achieving material savings, the limitations of mass production became evident in this study [44]. This highlighted an issue that needs to be addressed within the ready-to-wear clothing industry.

Carrico and Greensbora developed the 'amethyst evolution' method as a solution to the problem of inefficient use of time and unsuitability for mass production, which emerged in studies on zero waste pattern design. It is a sizing study that can be considered within the scope of the Multiple cloth approach method through size grouping, and which can enable a single design pattern to be adapted to different body groups. The main pattern of the design, which was prepared with a focus on sportswear, was worked for woven fabric, and knitted strips were used to be positioned in certain strategic areas for different body sizes [52].

Figure 14. "One square fits all" collection by Karin Vlug [51].

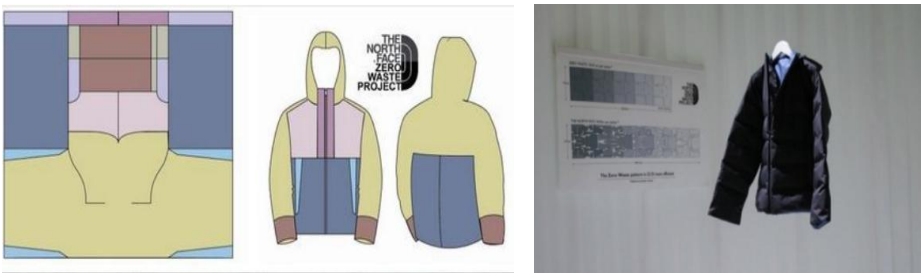

Figure 15. Jacket design made in collaboration with David Telfer and the North Face brand [44].

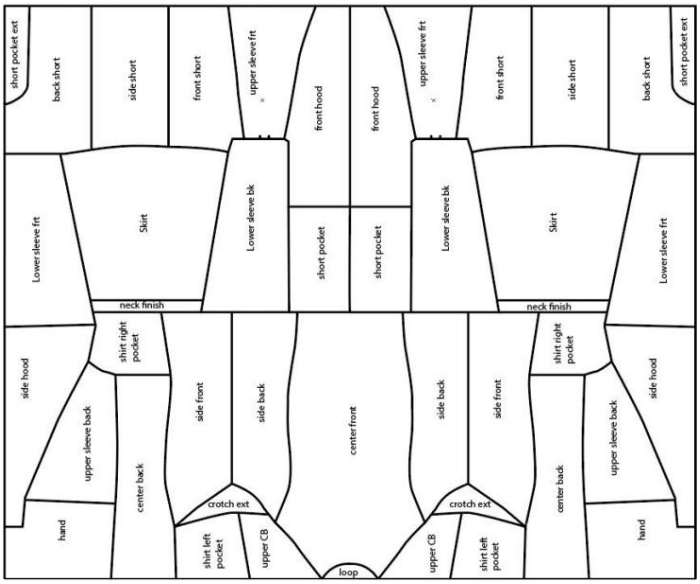

Figure 16. Pattern arrangement of the design made with the 'Amethyst Evolution' method on the fabric [52].

Figure 17. Activewear designed with the 'Amethyst Evolution' method by Carrico and Greensbora [53].

4.2. Material Usage and Efficiency

Solving the waste problem directly through the pattern in the garment design process can cause design limitations. Therefore, another area of study is to investigate what different efficient ways of using fabric can be in eliminating the waste problem instead of directly pattern-focused design.

It is one of the closest methods to mass production methods because of the placement of multiple clothing models in a single plane. In terms of both functionality and cost savings, 'multiple clothing production' can be one of the first choice methods when designing for mass. However, it is not possible to achieve zero waste control exactly as it is with jigsaw methods [40].

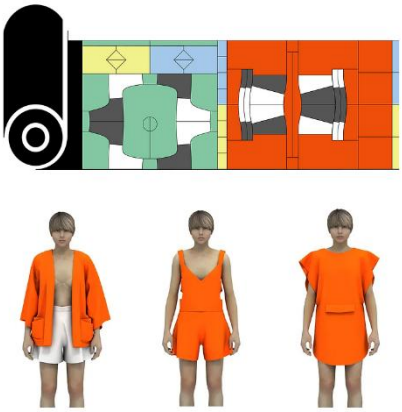

Figure 18. Placing patterns of different designs on the fabric surface by grouping them in a way that will not cause any waste [54].

The A020 system, developed by Danielle Elsener, is based on a series of templates aimed at eliminating waste. A020 templates eliminate the need for paper patterns. The developed templates assist designers in approaching a piece of fabric like a puzzle, where any leftover scrap can serve for purpose in a different clothing. In addition to making this system known to different designers, Elsener conducts a series of workshops to gather feedback for its improvement. Through these feedback circles, she aims to enhance the system, making sustainable designs more seamlessly adaptable to the mass production cycle [55].

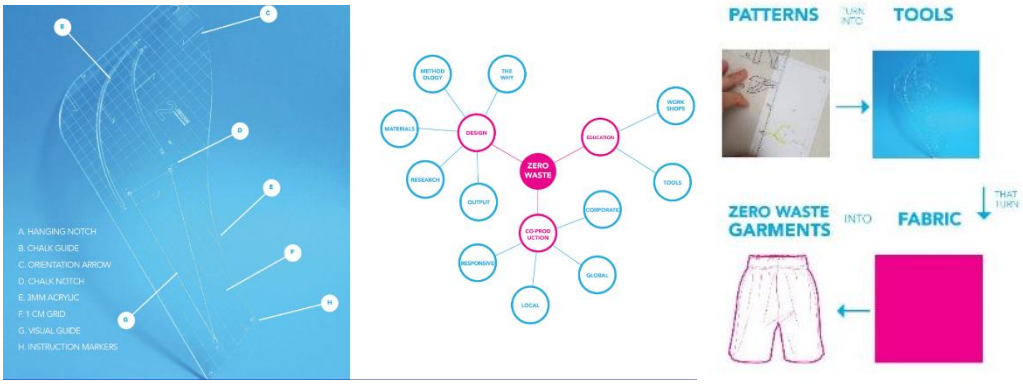

Figure 19. A020 zero waste patterning system developed by Danielle-Elsener [55].

Figure 20. Designs developed with the template system to use the remaining fabric pieces after the pattern in other garments [56].

This system aims to enable designers to improve their design processes continuously by bringing together various perspectives and expertise. It is a platform for designers from different fields to develop solutions for sustainability goals such as improving design processes, increasing material efficiency and reducing waste by benefiting from each other's experiences.

4.3. Modular and Transformable Design

Modular and transformable designs contribute significantly to the concept of sustainable fashion by enabling the development of products that can serve multiple functions. This approach aims to design garments in a modular structure, allowing them to be used or transformed in various ways. The ability of a single garment to have multiple functions not only maintains user interest in the product but also enables active participation in the design process. By transforming the product into different forms based on personal preferences, users are encouraged to express creativity and establish a personal connection with the garment. This design approach, depending on the characteristics of the selected materials, extends the product's life cycle and supports the creation of longer-lasting, eco-friendly products.

McQuillan pointed out that designers focus on the practice of designing one clothing at a time, so a second design that can be developed over another design is ignored. With the designs she developed, she made it possible to place another design pattern inside the jigsaw patterns. Holly and Rissanen co-curated Yield: Making Fashion Without Waste, the first contemporary exhibition to focus on zero-waste fashion, and developed the award-winning open-source zero-waste resource Make/Use.

Make/Use is an open source system that supports the production of user-replaceable and zero-waste clothings. Functioning as a user-centered toolkit, Make/Use allows consumers to participate in the creation of the clothings they wear. Each clothing is simple to make and can be modified in various ways to suit changing fashions and wearer needs [58].

4.4. Interdisciplinary Technologies and Zero Waste Approach

The zero-waste approach in sustainable fashion design has been enriched by production methods developed by designers inspired by technologies used in different disciplines. In this context, the "Smart Fashion Production" technique, developed by Karin Vlug and Laura Dunker in 2014, stands out as an innovative solution that rethinks traditional production processes and minimizes waste. Such innovative zero-waste solutions, developed by utilizing science, mathematics, and technology in fashion design, aim to optimize material usage and reduce environmental impact by integrating into production processes. The integration of modern technologies, such as laser cutting, 3D modeling, and 3D printing, alongside scientific approaches into the design processes, contributes to sustainable fashion from an interdisciplinary perspective. These technologies offer designers new opportunities to enhance production efficiency and prevent material waste, playing a crucial role in achieving zero-waste goals.

Karin Vlug, who has been working as a designer and researcher in the fields of biodesign, future materials, and production innovation in textiles and fashion since 2014, and industrial designer Laura Dunker (AMFI) developed a project called “Smart Fashion Production” in 2014–2015. Smart Fashion Production emerges as a new fashion production system that goes beyond traditional methods such as pattern making and sewing. It includes a system focused on production according to the local demand and body size of the person. The designs are rooted in personal, three-dimensional body scans to create clothings that offer an impeccable fit. Vlug states that the inspiration for developing the project came from the injection patterning industry, outside the fashion industry. With reference to the injection patterning method (liquid mass -> shaped product), which can produce products in very complex shapes by injecting heat-melted plastic materials into a pattern, cooling, and solidifying, a technique has been developed that can produce sweaters with an aesthetic, textured, and soft touch [59].

First, personal body measurements are scanned, modeled, and patterned by CAD CAM systems. Chemical solutions are then prepared in accordance with the characteristics of the three-dimensional model, and both the fabric itself and the clothing form are produced at the same time [41]. Vlug and Dunker collaborate with ArtEZ, CoE Future Makers, AMFI, ACIN, Modint, Maan R&D, Sizing Science, and Optimal Forming Solutions.

Another Smart Fashion Production system developed in 2016-2017 is a research project based on the development of a felting machine (woolfelting), which can provide felting of wool in a certain form. Collaboration with Vlug, Laura Dunker, Irene Maldini (HvA), Ellen Mensink (Loopalife), and Sebastiaan Boers (Optimal/Demcon). With Sebastiaan Boers’ flexible Optimal technology, clothing forms are obtained by felting Loopalife’s recycled wool fibers on a 3D modeled surface [42].

Figure 21.Make/Use Dress Design, Holly McQuillan, 2018 [57,58].

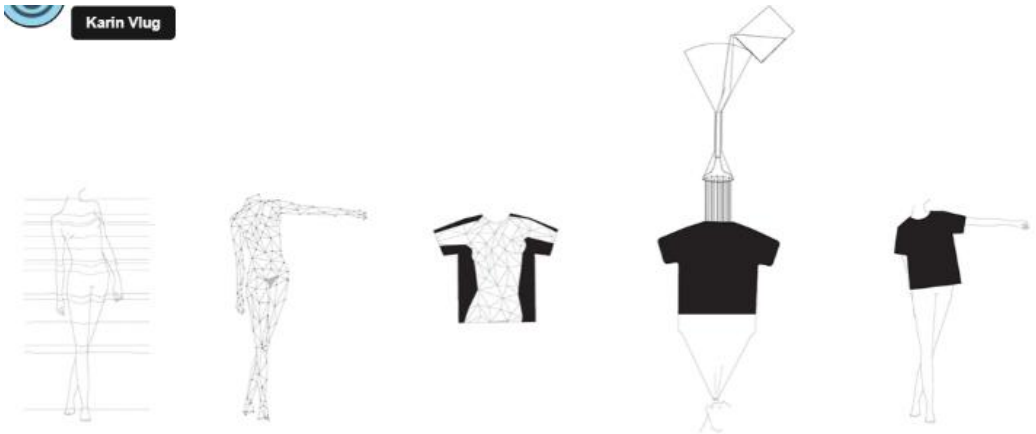

Figure 22. "Smart Fashion Production" technique developed by Karin Vlug and Laura Dunker in 2014 [60].

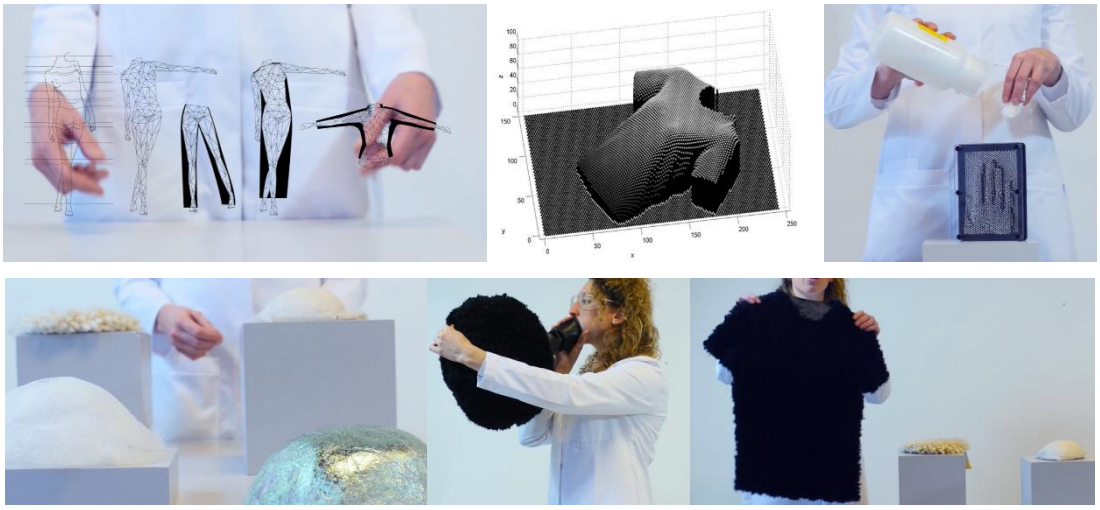

Figure 23. "Smart Fashion Production" technique developed by Karin Vlug and Laura Dunker in 2014 [61].

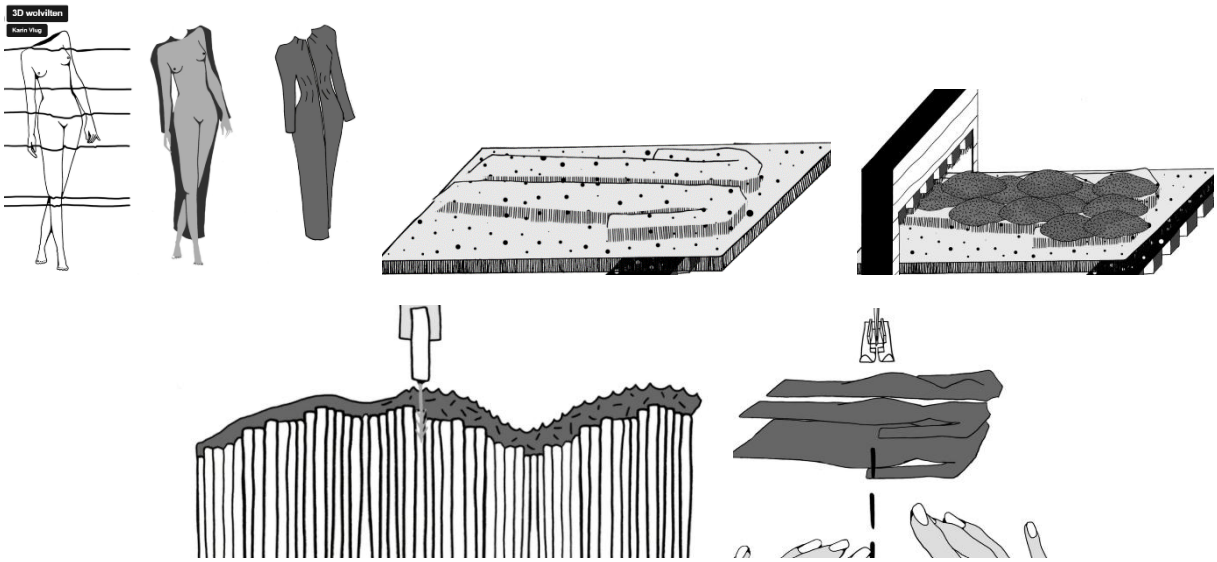

Figure 24. 3D Wolvilten, Karin Vlug [42].

5. DISCUSSION AND CONCLUSION

This study presents designers perspectives and solution proposals focused on the zero-waste approach in sustainable fashion design. The preventive measures and strategies that designers can implement in this process are primarily evaluated in the context of efficient material use, pattern-cutting-binding-focused designs, modular design, and interdisciplinary technologies. These solutions have both advantages and disadvantages in terms of their adaptability to mass production. It is possible to benefit from pre-consumer zero-waste solutions depending on the nature of the material, the scale of the design, and the purpose of the product. For example, researchers such as McQuillan (2022) and Rissanen (2019) have demonstrated how zero-waste design can reduce material waste and align with circular economy principles. Although significant research and innovative practices in zero-waste fashion design exist, the widespread adoption of these methods in the industry remains limited. Integrating these approaches into mass production processes presents challenges in terms of production efficiency and cost-effectiveness. These constraints arise from the specialized nature of production processes and the limitations of existing technologies. However, research on pre-consumer zero-waste fashion design may pave the way for designs that can be adapted to mass production and lay the groundwork for innovative ideas as alternatives to traditional production methods.

For instance, interdisciplinary collaboration between designers and engineers, as seen in Smart Fashion Production, can spark interest in developing sustainable production technologies within existing systems. The A020 system, developed by Elsener, may provide designers with access to numerous design templates, allowing them to embrace sustainable design principles without limiting their creativity. Beyond functioning as a platform providing access to design templates, this system can be viewed as an innovation model that fosters collective consciousness among designers, centers sustainability, and enables designers to achieve more effective and technological results through collaboration.

In this sense, encouraging interdisciplinary studies in the field of zero-waste fashion design may offer potential solutions to overcoming these challenges. Proposals developed through the collaboration of different disciplines, combining material sciences and technology with design, may accelerate the industry's adaptation to the zero-waste design concept. The widespread adoption of sustainability in the fashion industry will only be possible through the involvement of not only designers but also manufacturers and consumers. While designers must consider material efficiency and environmental impacts during the design process, manufacturers should adapt these innovative approaches to large-scale production, and consumers should support this cycle by demanding sustainable products. Ultimately, sustainability is not merely a design strategy but a holistic approach requiring the collaboration of all stakeholders. In this context, zero-waste fashion design should be considered not only an aesthetic innovation applied to garment form but also a strategic tool contributing to environmental sustainability.

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