SUSTAINABLE FUTURES IN FASHION & TEXTILE

FACTS

SERBIA FASHION WEEK

INTERNATIONAL CONFERENCE

# PROCEEDINGS

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TEXTILE SCIENCE AND ECONOMY

ZRENJANIN 25th OCTOBER 2024.

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# TEXTILE SCIENCE AND ECONOMY

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- **Fashion Apparel Cluster of Serbia „FACTS“,**
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## INTRODUCTION

Technical faculty “Mihajlo Pupin” University of Novi Sad has organised the 14th International Conference “ Textile Science and Economy ” held on October 25th, 2024, at the Technical Faculty “Mihajlo Pupin,” University of Novi Sad, Zrenjanin, Serbia. This conference brought together leading researchers and professionals from the textile industry, fostering an environment for the exchange of innovative ideas and advancements across various fields.

The conference featured a series of insightful presentations from distinguished speakers, including:

- **Mirjana Kovačević**, Serbian Chamber of Commerce
- **Slađana Milojević**, Cluster of the Fashion and Textile Industry "FACTS," Serbia
- **Aleksandar Žertovski**, Dell’orco & Villani, Italy
- **Riccardo Cavalleri**, Emmebi Impianti, Italy
- **Milan Zelović**, PuzzleFit AI, Serbia
- **Giacomo Nicolini**, Audaces Europ Srl, Italy
- **Ivana Šoštar**, Rigo, Slovenia

These speakers provided valuable insights into the economic aspects of the textile industry, addressing current challenges and opportunities. Their presentations laid the groundwork for fruitful discussions on how to enhance the economic viability and competitiveness of the textile sector.

During the conference, participants engaged in discussions that explored new approaches in textile materials, technologies, and business models that aim to tackle the pressing issues in the industry. The insights gained from these discussions provide valuable guidelines for future initiatives aimed at enhancing the efficiency and competitiveness of Serbia's textile and garment industry.

The hybrid format of the conference facilitated broader participation, allowing attendees to engage both in-person and online. This inclusivity ensured a dynamic and interactive experience, connecting experts and researchers without geographical limitations.

We are proud to note the involvement of over 40 attendies from both domestic and international institutions, highlighting the conference's role in promoting student engagement in research and professional activities. The event featured 34 full papers and 4 abstracts from a diverse range of countries, demonstrating the global interest in textile science.

The conclusions drawn from the conference underscored the significance of building partnerships with institiuion and industry stakeholders, establishing new contacts with leading institutions, and promoting student involvement in scientific research. We believe that these efforts will lead to increased innovation and collaboration, ultimately benefiting the textile industry as a whole.

I hope that this book of proceedings serves as a valuable resource for researchers, practitioners, and students alike, contributing to the ongoing discourse in textile science and economy.

Thank you to all participants, contributors, and supporters for making TNP 2024 a success.

The Chairman of the Organizing Committee:

**Maria Pešić, PhD**

Zrenjanin, 7th November, 2024.

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# RETAIL AND SUSTAINABLE SERVICE SYSTEMS: A PROMISING ALLIANCE FOR THE FASHION SYSTEM. FROM THEORY TO PRACTICE

**Alessandra Spagnoli**
Politecnico di Milano, Italy

## ABSTRACT

This article explores the role of servitisation in promoting sustainability in the fashion retail sector, highlighting the transition from product-based to service-based business models. Servitisation enables retailers to extend the life cycle of products by offering services such as repair, rental and recycling, which support the principles of the circular economy. By developing an ontology of sustainable service systems, this research provides a framework that identifies how retail can promote sustainable practices throughout the fashion value chain. Through applied and design-driven activities, the study examines the implementation of sustainability services, focusing on how retail spaces can act as platforms to promote sustainable practices that impact the fashion value chain. This research contributes to the growing body of knowledge on sustainable retail, offering insights into how retailers can play a central role in promoting environmental and social sustainability through service-oriented models.

**Key words**: fashion system, retail, servitisation, sustainability, applied research.

## INTRODUCTION

### Sustainable retail and service systems in fashion

The fashion industry, which contributes significantly to environmental degradation, has now recognised the need to address and promote a transformation of business and consumption models towards greater sustainability and circularity. This transformation, driven by environmental issues, consumer demand, the need for companies to remain competitive in a changing marketplace, and, last but not least, regulatory pressures, has pushed companies to experiment and implement circularity and sustainability strategies throughout the fashion value chain.

In this context, the retail sector, acting as an intermediary between producers and consumers, is also taking on a crucial role in the sustainable transformation of the fashion industry (Ruiz-Real et al., 2019; Yang et al., 2017), albeit with some delay compared to more established areas of research such as, for example, new sustainable materials or design for circularity. Indeed, retailers, thanks to their 'position' within the fashion chain, can influence both upstream (production) and downstream (consumption) practices, thus becoming key players in the transition towards sustainable and circular models (Vadakkepatt et al., 2021) capable of addressing the pressing environmental and social issues of the fashion system (Dragomir & Dumitru, 2022). In particular, the concept of *servitisation* – the transition from product-centred business models to those incorporating services – has gained ground as a means to promote circularity in the industry (Beuren et al., 2013). This shift to service-based systems referred to as *product-service systems* (PSSs), has encouraged the creation of business models that adopt circular economy principles, focusing on waste reduction, material reuse and product recycling (Potting et al., 2017). These practices are particularly significant in the fashion industry, where problems such as overproduction, short product life cycles and excess waste have led to substantial environmental impacts, including high carbon emissions, water consumption and pollution (Prado et al., 2022).
Servitisation represents a strategic shift from the traditional sale of products to providing services that increase product longevity and support circularity. In the fashion industry, servitisation can take many

forms, and retailers are well positioned to drive the adoption of circular practices. By offering, among others, services such as repairing, refurbishing and reselling (Lang & Armstrong, 2018; Vadakkepatt et al., 2021), retailers can extend the useful life of fashion products, thereby reducing demand for new materials and decreasing waste levels (Prado et al., 2022). These services not only provide consumers with more sustainable options but can also encourage a change in consumer behaviour towards more responsible consumption (Spagnoli & Iannilli, 2023). Furthermore, sustainable retailing can support the development of new revenue streams through service-based offerings, which allow retailers to differentiate themselves in a competitive market (Macchion et al., 2018).

### Research aims and contributions

The article presents an investigation into retail's role in the fashion industry's sustainable transformation, focusing on integrating service-based systems to promote circular and more sustainable practices. The research aims to answer the question: What role does retail play in the context of sustainable transformation? How can implementing service systems for retail trigger more sustainable and circular processes?

These questions are explored in the context of the NRRP "MUSA – Multilayered Urban Sustainability Actions" project, Spoke 5 – Sustainable Fashion, Luxury and Design.[1] The study emphasises the importance of design-led innovation in shaping retail service systems that extend the life cycle of products, minimise waste and support the transition to circular business models while promoting a culture of sustainability and more equitable social practices.

The research framework is based on developing an ontology of sustainable service systems targeted at the retail sector and structured around three key areas: environmental sustainability, culture of sustainability, and social sustainability. These areas are further divided into specific service categories that include circular practices, as well as consumer education and community involvement (Elli et al., 2024). The framework serves as a basis for understanding how retail can promote sustainable practices throughout the fashion value chain, from production to consumption.

By focusing on the design and implementation of sustainable service systems, the research aims to provide insights into how retail can act as a catalyst for sustainability in fashion. Through applied research, including a collaboration with leading sustainable fashion brand Stella McCartney, the research examines practical applications of the framework to bridge the gap between theory and practice in sustainable retail.

## RESEARCH METHODOLOGY

This research methodology is structured around two main research actions: (i) the development of an ontology of sustainable service systems for fashion retail and (ii) the application of this ontology to feed bespoke and case-specific applied research on sustainable service systems for fashion retail.

The ontology (called 'Sustainable Retail Model') is based on a comprehensive mapping of more than 370 sustainability-oriented initiatives across Europe extensively described in Elli et al. (2024). The mapping identified three main areas within the ontology: services for environmental sustainability, culture of sustainability, and social sustainability. Each area includes specific categories of services that support circular and more sustainable processes.

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[1] The research is carried out by the research group of the Design Department of the Politecnico di Milano within WP2 - T5.9 'Development of an Innovative Sustainable Design-Driven Retail and Service Model' and T5.10 'Sustainable Design-Driven Retail and Service Model Toolkit'.

The ontology was constructed through a multi-stage process:
*Case study analysis*: The first phase involved collecting data on various sustainable retail practices through a literature review and netnographic research. The cases ranged from local sustainable retailers to large international brands, covering practices as diverse as rental services, digital garment management tools and repair initiatives.

*Categorisation*: The collected data were categorised into specific service types. These categories formed the basis of the ontology, capturing the essential characteristics of different sustainable retail practices.

*Validation and refinement*: The proposed ontology was then validated and refined through focus group activities involving fashion and sustainability professionals.

The practical application of the ontology was tested in collaboration with Stella McCartney, a leader in sustainable fashion. Stella McCartney is a leading sustainable fashion brand known for its pioneering use of environmentally friendly materials and strong supply chain transparency. The company has established itself at the forefront of sustainable innovation, incorporating organic cotton, recycled fibres and new experimental materials while avoiding animal products such as leather and fur (Campos Franco et al., 2020). However, although the company is pioneering sustainable sourcing and production practices, structured efforts to harness retail as a strategic channel to promote sustainability have been limited. Retail spaces and service models remain underutilised opportunities to implement circular principles and extend sustainability beyond materials and supply chain management. For this reason, Stella McCartney is an ideal partner for the NRRP MUSA research project, which aims to integrate innovative sustainable practices within retail environments. The brand’s commitment to sustainability aligns with the project’s goals of establishing retail as a platform for meaningful and sustainable innovation, thus extending its sustainability strategy to the retail environment.

The brand participated in a participatory activity organised by the research team to explore innovative service solutions for sustainable retail. The participatory activity involved Stella McCartney’s teams in Italy and the UK, including representatives from the sustainability, retail operations and product innovation departments. The session aimed to identify and implement service systems that could be integrated into Stella McCartney’s retail strategies. This collaboration provided insights into how sustainable retail models work and highlighted areas for future development. These include the development of both tools to facilitate the adoption of sustainable practices in different retail contexts and applied research projects to design and pilot the proposed services.

## RESULTS AND DISCUSSION

### The ‘Sustainable Retail Model’: framing theoretical concepts

The construction of the ontology of sustainable retail service systems followed a process of progressive aggregation and recombination of insights derived from research on real case studies. This research began with a focus on the traditional strategic levers associated with implementing environmental sustainability in line with circular economy principles. As a critical interface between production and consumption, retail is increasingly recognised as a significant catalyst for advancing circular economy processes (Poldner et al., 2022). The core principle of the research was to investigate how, through the implementation of services that correspond to the 3Rs of circularity – reduce, reuse and recycle – together with the concept of Rethink aimed at product redesign, retail could play a crucial role in both extending product lifetimes and minimising waste.

#### *The role of the 3Rs and Rethink in retail sustainability*

The principles of reduce, reuse and recycle are the fundamental pillars of circular economy strategies (Ellen MacArthur Foundation, 2013). Each principle has distinct implications for how retail spaces can contribute to sustainability:
'Reduce' principle implies decreasing the amount of new products entering the market or reducing dependence on new raw materials. By reducing resource consumption, retailers can significantly decrease the environmental impact of production, thus supporting sustainable consumption patterns. For example, adopting minimal packaging and promoting products made with fewer resources can directly contribute to waste reduction.

'Reuse' practice includes the continued use of products that have yet to end their useful life, including sold items and unsold stock. Retail can facilitate the recovery and redistribution of these products, thus preventing them from becoming waste. Reuse-oriented services, such as rental systems and second-hand markets, have emerged as effective strategies to extend the life of products.

'Recycling' involves reintroducing end-of-life products back into the production cycle (within the fashion value chain or other production cycles, such as construction) to minimise waste and resource depletion. Retail may mean offering take-back programmes or partnering with recycling facilities to process used products, converting them into new products or raw materials.

Finally, extending beyond the traditional 3Rs, 'Rethink' encourages the reuse of unsold objects, post-consumer waste or products with 'emotional' or cultural significance, increasing their symbolic value or integrating them into new design narratives. This approach promotes creativity and innovation, allowing retailers to find new ways to revitalise products that would otherwise be discarded.

Adopting circular economy principles within the retail space, be it physical, digital or omnichannel, enables sustainability processes beyond individual products. The investigation of strategies related to the 3Rs and Rethink revealed the potential of retail environments as platforms for the promotion of a significant number of sustainable retail service systems, many of which can be traced back to the broader 9R framework (Potting et al., 2017), such as repair, refurbishment, or on-demand manufacturing. All these practices have been reorganised within the sustainable service systems' ontology to capture how retail can catalyse sustainability and highlight impacts on all stakeholders in the fashion value chain. For example, offering in-store repair services not only extends the life of products but also reinforces the retailer's commitment to sustainability, increasing brand loyalty and consumer trust. Furthermore, by integrating circular strategies into their operations, retailers can facilitate consumer engagement in sustainable practices and act as educational centres that inform and influence consumer behaviour towards more sustainable choices.

The research highlighted a critical aspect of the transition towards sustainability in the retail sector. Indeed, this transition is possible and more effective when it takes place in a context of socio-institutional change, which includes changes in regulations, standards, production practices, consumer behaviour and cultural norms. The integration of circular economy principles into retail requires not only technological and operational innovations but also changes in the way sustainability is perceived and practised along the value chain (Vecchi, 2020).

***Expansion of ontology to social sustainability and culture of sustainability.***

From this initial reflection, and in response to the evidence from the research of real application cases, the initial mapping of the ontology, which was narrowly focused on circular economy-related strategies, was subsequently expanded to include other forms of sustainable practices in which retail plays a facilitating role. The ontology was thus expanded to include 'culture of sustainability' and 'social sustainability' as core pillars.

The 'culture of sustainability' category includes services that utilise the strategic position of retailers within the value chain to promote sustainability awareness. Retailers can use communication, education and product assets to engage consumers and foster a deeper understanding of sustainable practices. There are two main orientations within this category: practices aimed at improving the retailer's sustainable operations, such as improving transparency through supply chain monitoring and disclosure, and consumer-facing practices that use the retail environment as a medium to raise public awareness and education on sustainability issues.

Finally, the 'social sustainability' category includes services that promote social equity, such as ensuring fair labour practices and supporting vulnerable groups. In many cases, these services are not stand-alone. Instead, they are service strategies that are activated through partnerships with social enterprises or non-profit organisations whose mission is to generate positive social impacts. For example, partnerships with charities to donate surplus stock or programmes to support community employment initiatives reflect a commitment to social sustainability. In this specific case, it is a 'way' to activate practices and services that have an impact beyond the system of stakeholders traditionally involved in the fashion value chain.

Figure 1 illustrates how various practices and strategies can contribute to a more sustainable fashion system by acting from the retail space and connecting the different dimensions of environmental, social and culture of sustainability. The retail environment serves as a convergence point for these dimensions, providing a valuable platform for integrating sustainable strategies into fashion business practices.

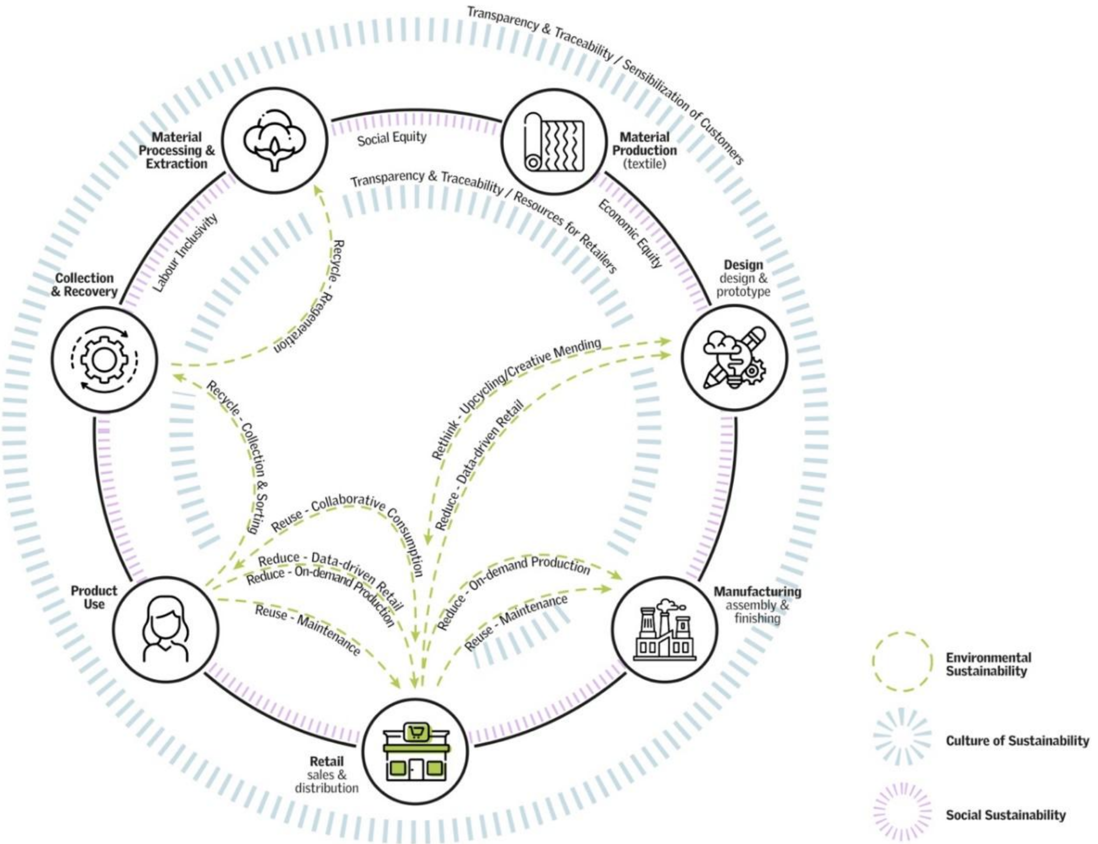


*Figure 1: Sustainable Retail Model: connection among the different dimensions of environmental, social and culture of sustainability.*

**In-store Sustainability Narratives: developing applied experimentation**

Based on the ontology described above, the sustainable retail model, operationalised as a co-design tool, was tested in collaboration with the sustainable fashion brand Stella McCartney. This participatory co-design activity has enabled the identification of shared and promising innovation trajectories through which the company seeks to experiment with more sustainable and circular retail processes.

One of the most promising areas currently being explored by the research team and the company is the enhancement of the role of the store as a communicative agent, both tangible and intangible. The aim is to convey the brand's sustainability values, practices, processes and innovations through the retail environment, effectively positioning it as a medium for conveying sustainability. This approach goes beyond traditional communication, incorporating tangible elements such as installations, product samples and immersive showcases. These elements offer consumers direct experiences, allowing them to confront sustainable materials, observe production processes or experience virtual simulations of the brand's sustainable practices. By creating a sensory and hands-on experience, a brand like Stella McCartney has the potential to deepen consumers' understanding and appreciation of sustainability, fostering a long-term commitment to sustainable consumption.

***Sustainability awareness via in-store narratives***

The physical retail space is recognised as an essential interface between retailers and consumers, and in acting as a key point of contact for communicating brand values, it now assumes indispensable relevance when these values are aligned or must align with sustainability. For this reason, the retail space can be a powerful medium for translating abstract sustainability goals into tangible actions, fostering consumer understanding of engaging in sustainable awareness (Fuentes & Fredriksson, 2016; Lehner, 2015).

Although today, the potential of the retail environment to promote sustainability is increasingly recognised, the actual implementation of strategies aligned with this goal is often inconsistent and lacks the depth necessary to promote meaningful consumer engagement (Lin et al., 2022). The difficulty retailers face is twofold: on the one hand, the complexity of sustainability itself poses challenges; on the other hand, the in-store conveyance of sustainability services impacts different levels of company management.

Concerning the inherent complexity of sustainability strategies, such as circular economy practices or ethical sourcing, their 'translation' into messages easily implemented and understood by consumers is challenging (Lehner, 2015). They are often highly technical in terms of both language and procedural. However, this same technicality is crucial in guaranteeing the transparency and correctness of processes that imply sustainable and circular practices. Therefore, the alignment of languages and narratives requires an effort involving the various levels of the company, from product management to the retail, and is also linked to the practical realities of consumer behaviour and market demand.

Concerning the in-store conveyance of sustainable services, for example after-sales services such as take-back systems or second-hand retail, the involvement of stores in implementing these initiatives varies considerably. Indeed, responsibility for implementing sustainability initiatives is often split between the corporate and the in-store level, leading to inconsistent messages and missed opportunities for consumer engagement.

***Building a 'Abacus of Modular Narratives' to foster in-store sustainable communication***

In order to explore innovative in-store experiential communication systems and effectively convey sustainability issues, a tool called the 'Abacus of Modular Narratives' is being developed and refined. This tool serves to structure the research process and guide the design of innovative and customised in-store communication solutions. Conceptually, the abacus is built on a matrix of three axes, each corresponding to a variable identifying a specific mode of engagement within the retail environment.

The first variable is the *spatial dimension* of the retail environment. The spatial dimension includes all touch points - both physical and digital - that can support the sustainability narrative. These touch points range from traditional elements such as panels and displays to more interactive features such as QR codes, mobile applications and digital screens. These media allow the narrative to 'come to life' in various forms, engaging the consumer in an immersive experience.

The second variable concerns the *subject of the narrative*, which may be associated with the product itself, the design or production process, or the service system offered. This dimension allows the narrative to focus on different aspects of sustainability, such as material innovation, ethical production or circular economy practices. By focusing on a specific topic, the retailer can adapt the narrative to highlight critical aspects of its sustainability efforts, thereby increasing transparency and consumer engagement.

The third variable concerns the *narrative structure*, which refers to how the message is conveyed within the retail space. The narrative can range from an informative structure providing facts to a persuasive approach encouraging behavioural change or an evocative style connecting emotionally with the consumer. Other options include educational methods that educate consumers or analytical approaches that provide a deeper understanding of the product life cycle or sustainability strategy.
Combining these three variables - spatial dimension, narrative subject and narrative structure - generates a wide range of design trajectories. These trajectories serve as guidelines for co-design with the company, enabling the development of a pilot solution to be tested in the Stella McCartney store in Milan.

The 'Abacus of Modular Narratives' development addresses the growing need for retailers to effectively communicate their sustainability strategies in ways that resonate with consumers. Traditional methods of in-store communication, such as signage and labels, often lack the depth and personalisation needed to foster a meaningful connection between the consumer and the brand's sustainability efforts (Fuentes & Fredriksson, 2016). The abacus fills this gap by providing a systematic framework through which retailers can tailor their sustainability messages to their customers' specific interests and behaviours.

Using different combinations of spatial tools, narrative topics and structures, retailers can create a more engaging and immersive experience. For example, a physical display illustrating a product's lifecycle, combined with interactive digital elements that allow customers to explore sourcing and production processes, can provide a multi-layered understanding of the brand's commitment to sustainability. This approach also adapts to consumer preferences; some customers may prefer concrete and direct information, while emotional or experiential elements may influence others more.

Furthermore, the abacus encourages collaboration between retailers and designers to co-create customised solutions that reflect the brand's unique sustainability narrative. By involving the company in the co-design process, the solutions developed are not only aligned with the brand's sustainability goals. Still, they are also practical and viable in an actual retail environment. This co-creation process ensures that the narrative resonates authentically with both the brand and customers, fostering trust and enhancing the overall consumer experience.

## CONCLUSION

This research highlights the significant role that servitisation and service-based models can play in promoting sustainability in the fashion retail sector. By developing an ontology that organises sustainable retail practices across environmental, cultural and social dimensions, the study provides a practical framework for retailers to enhance their sustainability efforts. The results show how retail spaces can effectively integrate circular economy principles and reduce resource use, minimise waste, and promote sustainable awareness. The collaboration with Stella McCartney underlines the potential of retail in showcasing sustainable practices and acting as a catalyst for a broader system-wide transformation. Although implementing these models presents challenges, the research emphasises that retailers have a unique opportunity to influence the fashion industry's transition to more sustainable processes. By embracing service-based strategies, retailers can foster a deeper connection to sustainability and drive positive long-term environmental and social impacts.

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# FASHION PRODUCTS IN THE AREA OF DIGITAL MANUFACTURING – 3D PRINTING

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## ABSTRACT

Various fashion products such as garments and footwear have seen tremendous changes due to digital manufacturing. Mayor global players in the apparel industry have been long embedding in the inclusion of digital tools in their product development. These digital technologies as part of Industry 4.0 promise to overcome challenges related to waste and pollution by sustaining sustainable production. The rapid maturity of new technologies brings creative and innovative solutions for product development where customization enhances material use and waste reduction.
3D printing is a form of additive manufacturing with various applications in the fashion industry that have attracted interest from academia and industry. It can help to improve and add functionalities to products. Creative designers and well-known brands have been implemented to create new and innovative fashion products. The combinations of 3D printing materials with textile fabrics create composite structures that can be further used for applications such as smart textiles. Other applications are footwear products, where 3D printing provides customized products to improve fit and comfort. Fashion accessories present other interesting applications of 3D printing in the fashion industry, where various creative ideas can be produced with additive technologies. Here, some key studies from 3D modeling, simulation, testing, and their production by additive manufacturing technology will be presented. Product customization has been the focus to contribute to sustainable production. It can provide new methodologies to foster productivity, customization, and sustainability.

**Key words**: digital manufacturing, 3D printing, textiles, footwear products, accessories, etc.

## INTRODUCTION

The digital transformation occurring in the fashion industry promises a great future. It encompasses various processes such as product design and manufacturing, marketing and retailing, etc. Many countries have embarrassed Industry 4.0 or even called smart manufacturing. Integrating multiple technologies to connect the physical with the virtual world facilitates interconnection and computerization in manufacturing (Zhang C., et al., 2021).

Studies conducted on the degree of implementations of digital technologies in the fashion industry recommend wider adoption of technologies such as blockchain; energy storage for smart clothing, integration of IoT, Artificial intelligence, etc., (Akram Shaik V., et al., 2022). Especially in the cases of companies that engage actively in the use of 3D technologies such as 3D modeling, simulation, 3D scanning, virtual and augmented reality, offer opportunities to reduce physical products, while improving business model innovations (Casciani D., et al., 2022). Moreover, implementing these technologies as the pillars of Industry 4.0 could reshape the fashion industry as a more sustainable and truly customer-driven business (Bertola P., et al., 2018). But at the same time, the eagerness to implement these digital technologies reveals the lack of workers’ skills and the need to gain these new skills by following training programs within the industry (Sayem A., et al., 2023).

In developing countries, the situation is different due to various barriers that should be overcome for the adaptation of Industry 4.0 (Rakesh D., et al., 2021). The advantages offered are numerous. However, still there is a low adaptation rate especially in SMEs, which encounter challenges like financial and knowledge constraints (Masood T., & Sonntag P., et al., 2020).

Sustainable production is a common definition used everywhere. It includes the way we produce, consume and live our life. Industry 4.0 plays a great role in sustainability in all industries. Studies reveal a significant impact on manufacturing sustainability in various stages (Jamwal A., et al., 2021). Especially, mobile technology, nanotechnology, simulation, and drones have the highest impact including the apparel and footwear industry (Chunguang B., et al., 2020). To stay competitive, adaptation of Industry 4.0 is the first step to be taken by supply chains (Dalmarco G., & Barros A., et al., 2018), to provide better service and increase consumer experience (Majeed A. Aabid M., & Rupasinghe Th., 2017).

## 3D PRINTING – NEW METHODOLOGIES TO FOSTER PRODUCTIVITY, CUSTOMIZATION, AND SUSTAINABILITY

The main pillars of Industry 4.0 include 3D printing technology, which is well known for with wide applications in various industries. It provides immersive opportunities not only in creativity but offering a more sustainable way of manufacturing. This is highly important for the fashion industry, which is ranked among the first places for the negative contribution.

Fashion is one of the industries where innovation and creativity are the main factors that drive changes, and 3D printing technology promises a great future. The diffusion of 3D printing technology for various fashion products continues due to the development of 3D printing machines and materials.
During the 3D printing process some steps needed to be followed to produce the final product. As a digital technology, the first step includes creating the 3D model. Various software can be included in this process, but at the end, each of them should convert the 3D model into one of the additive manufacturing formats. Secondly, the 3D model designed for the 3D printing process is imported into the 3D printer software, which prepares for 3D printing process. During this step, different 3D printing parameters related to the machine, material use, and the product destination are selected before starting the 3D printing process.  The third and the last include the 3D printing process, where successive layers of melted material are spread from the nozzle and following the geometry of the section plane. Figure 1 presents Fish diagram of factors affecting 3D printing process.

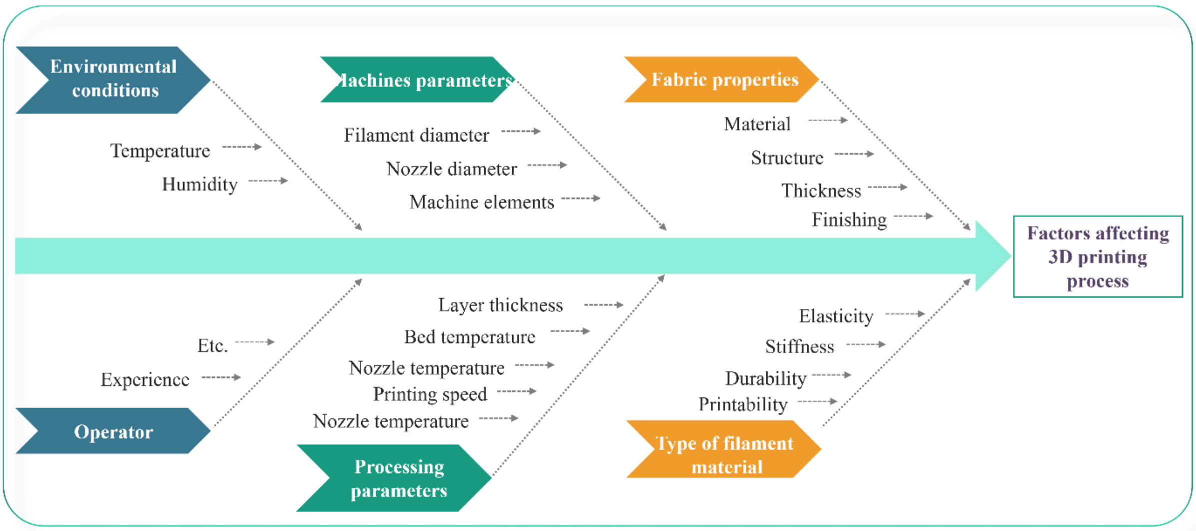


*Figure 1: Fish diagram of factors affecting 3D printing process.*

Stratasys is a well-known company for 3D printing technologies that is revolutionizing the fashion industry. 3D fashion launched by this company experimented with 3D printing on textile fabric to create print with full color and clear print, for very creative designs and a degree of optical illusions effects on the garments produced by these fabrics. Moreover, it is used for other products such as footwear or accessories (Stratasys, 2024). The number of fashion designers or brands that have experimented with 3D printing technology depicts a rising interest in bringing consumers creative and innovative products. The following figure presents some key studies of the implementation of 3D printing for garment parts printed separately and assembled with the garments. Cases of letters to personalize different garments, or 3D printed model of flower of life are visible on the left and center part of the figure. Meanwhile, the last cases present other interesting applications, where modeled geometries are 3D printed on textile fabric and the dress produced. Also here is visible the bag produced with where the Albanian flag is 3D printed on textile fabric. It is very important to emphasize that it includes several tests to evaluate the stability or adhesion of 3D printed material on textile fabric.


*Figure 2: 3D printing parts for garments and 3D printed geometries on textile fabric* (Spahiu T., et al., 2020), (Spahiu T., et al., 2020).

Another important application are footwear products. These products are among the most distinguished for the implementation of 3D printing to the manufacturing process, especially for athletic shoes. These types of shoes have a high rise, that can be explained with the fit and comfort they offer and the gained interest from consumers for the benefits offered by these products. According to the market analyses, it is expected to grow at a CAGR of 6.86% during the forecast period (2024-2029) (Mordor Intelligence, 2024). The following figure depicts some key studies, where 3D models of shoe parts such as heels, or last used for footwear production are produced by additive manufacturing or 3D printing technology. Creative designs derived from inspirations from various sources are ready to be used for footwear production. Even during this process, the created prototype needs to be tested or simulated to fulfill requirements for the stability and fit of footwear products.

*Figure 3: 3D printed shoe parts as heels and shoe last* (Spahiu T., et al., 2024).

3D printed accessories are other applications of 3D printing technology in the fashion industry. Complex geometries can be modeled and produced by additive manufacturing. Moreover, customization and waste reduction can be easily achieved. Figure 4 presents 3D modeled accessories aim to manufacture by 3D printing process. The creativity and complex geometries can be easily realized by 3D printing, where customization takes an important place.

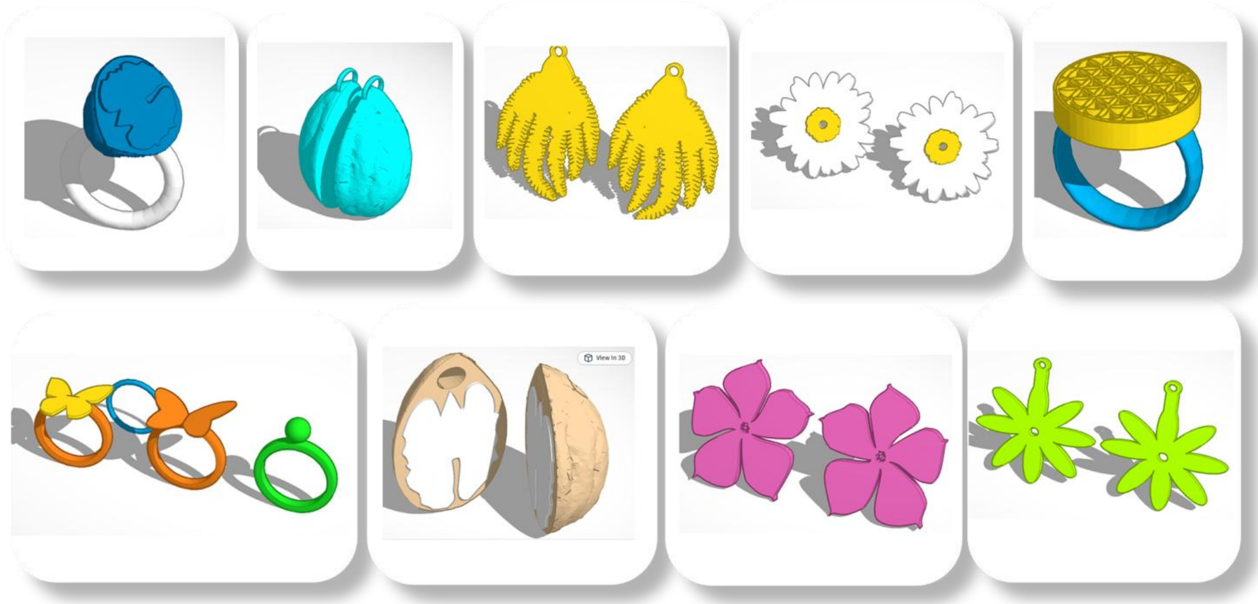

*Figure 4: 3D modeled accessories for printing process* (Spahiu T., et al., 2020), (Spahiu T., et al., 2021).

## CONCLUSIONS

Digital manufacturing is shaping the way of product development and offering to consumers, including garments, footwear, accessories, etc. Mayor global players in the apparel industry have been impacted on the inclusion of digital tools in their product development as an indispensable way to offer consumers product with the right fit and being competitive in the market. These digital technologies as part of Industry 4.0 are seen as a great promise to overcome various challenges in the fashion industry, where environmental impact is seen as the most change to lower it. The huge amount of waste has increased the attention of various actors to rethink the sustainable way of production. It acts as a driver and forces the need for change in business model practices and innovative solutions to make fashion sustainable, which is supported by the rapid maturity of new technologies. They bring creative and innovative solutions for product development where customization enhances material use and waste reduction.

Among these innovative technologies, 3D printing plays a major role in product development, to waste reduction. The wide spread of 3D printing technology brings evidence as 3D printed textiles, composite structures created by combining 3D printed geometries and textile fabrics, footwear products, or accessories. Its advantages are numerous, but waste reduction, customization, and producing products with complex geometries not produced by traditional manufacturing highlight its impact on revolutionizing the way various fashion products are created, produced, and offered to consumers. Some key studies from 3D modeling, simulation, testing, and their production by additive manufacturing technology were presented, with a focus on product customization for improving design or adding functionality with high speed and efficiency.

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# THE CONTRIBUTION OF DIGITAL TECHNOLOGY IN THE FIELD OF CLOTHING PRODUCTION FROM THE ASPECT OF ECOLOGY AND IN THE EDUCATION SYSTEM

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**ABSTRACT**

With the advent of digital technology in education and clothing production, there have been many positive changes. With the introduction of digital technology in the field of higher education, it is much easier for students to understand the course content and at the same time they are introduced to the world of digital fashion and keep up with the development of technology. The CLo3D computer program offers the opportunity to teach innovative content in the areas of construction, modeling and clothing design. One of the applications is in the area of the no-waste concept in terms of maximizing the use of patterns, greatly reducing or eliminating pattern waste, which has a positive impact on the disposal of textile waste.

**Key words**: digitization, teaching, zero waste

## INTRODUCTION

Digitalization represents a significant step in the modernization of the education system and adapts it to the digital transformation of society. This process involves the use of information technology and computer tools with the aim of improving teaching. Successful digitalization requires continuous investment in equipment and education. In the European Union, digitalization in education refers to solving numerous challenges facing the education sector, such as improving quality, personalizing access and relevance. The EU has therefore set a number of goals for digitalization in education, which aim to achieve the following: All citizens should have access to high-quality digital education, regardless of where they live or where they come from. Promote the use of digital technologies to improve learning and teaching, including the use of personalized learning adaptation, collaboration and game-based learning as well as various platforms.

Promote the development of digital skills and competences among students and teachers. Promoting innovation and entrepreneurship in the education sector through digital technologies. The Horizon project: European Academy for Young Designers to Study Innovative Technologies in Digital Fashion Design, abbreviated to FashionTex, in which the Faculty of Textile Technology is one of the partners, is presented in this article. Its main aim is to introduce computer programs into the teaching process. Since one of the most important programs at present is Clo3D, which is used in the industry for designing and modeling clothing, it is necessary for educational institutions to keep pace with the progress of technology.

One consequence of the application of this computer program in the field of the zero-waste concept is the reduction of textile waste, another topical issue in the field of clothing technology and industry in general. The application of digital technology in teaching in the field of garment construction, modeling and garment design and thus in the fashion industry is not yet at the same level as in other technologically advanced industries, and some of the reasons for this are the lack of access to digital technology, lack of knowledge and skills in the field of digital technology and, above all, resistance to the adoption of new technologies. Introducing and building an infrastructure with innovation and integration of digital technology, virtual reality in the process of developing fashion products, and new ways of communicating with consumers and selling through virtual platforms are just some of the possible directions for the transformation of the textile fashion industry, which is known as an extremely polluting industry of the new age that has great potential for the development and implementation of sustainable concepts for the development of production and sale of fashion products

(Rudrajeet Pat all, 2022.) Fashion, which has changed since the beginning of the industrial revolution under the influence of technological, social and economic changes, has accelerated significantly and has become accessible to a greater number of people. Due to the influence of fast fashion and rapidly changing fashion trends, consumers are buying more and more clothes, increasing production, which has a negative impact on the environment. The advantages of tailoring and manufacturing clothes according to the no-waste concept compared to basic construction lie in the observance of the basic principles of sustainable development. The negative impact on the environment is reduced, natural resources are conserved and the energy consumption required for production is reduced. Cutting loss is reduced, so that the amount of waste is already reduced in the production process. The use of fabrics is maximised and the design of the clothing is innovative (Farley Gordon, J.,Hill, C.,2014).

## 2. FASHION TEX PROJECT

In recent years, the textile industry, especially the fashion industry, has come under heavy criticism. Digitalization is advancing rapidly in all areas of society, including fashion design. Processes can be improved, waste reduced and traceability increased. In addition, the 3D construction of garments and the simulation of fabrics open up an endless playground for creations that are not limited by the gravity of the material. Old and new methods do not have to compete, but can challenge and enrich each other, leading to a more holistic and dynamic approach in the fashion and apparel industry.

FashionTEX is a 3-year project (2024.-2026.) that aims to create expertise at fashion universities and train students in digital fashion. It will add future-oriented and more sustainable content to the curricula. The fashion industry relies on digital fashion in all areas of the value cycle, from design to sales, and the technologies used are evolving rapidly. The analysis shows that education at fashion schools in Europe often lags behind what the industry has already implemented.The faculties are at very different stages with their training: some teach at an advanced level, others are still at the beginning of training for digital fashion. FashionTEX closes these gaps. In the future, the results of this project will be implemented and passed on to lecturers and students on the basis of a high-quality joint curriculum that enables a European student exchange. The career opportunities and competitive potential of graduates on the job market will increase significantly thanks to their expertise in the field of digital fashion.

### 2.1 Education and Introduction of the ClO3D Computer Program

In the aforementioned project, the main emphasis is placed on educating students in the computer program CLO3D, which is a computer program specialized in 3D clothing design, which is becoming an indispensable tool in the fashion industry and clothing design. Its purpose is to enable designers to visualize and test garments in a virtual environment. The program accelerates and optimizes the design and production process.

The predecessor of the CLO 3D program is the Marvelous Designer program, whose function was 3D designing cosplay costumes. The idea for Marvelous Designer was developed by a computer science student who saw the potential of such a program after the positive reactions of his colleagues. Over time, this program began to be used by clothing constructors, and from that came the idea to develop a program that is fully adapted to tailoring and designing clothes, and that's how CLO 3D was born. The goal of the program is to present the garment and material as realistically as possible. Although the program is relatively new, its use is becoming more widespread, with a trend of development (ClO3D, 2023)

One of the reasons for the application and popularity of this computer program is that it tries to make maximum use of the material (cut image), which directly affects the preservation of the environment in terms of reducing textile waste (inter-cut loss), which is extremely important in the textile industry.
The ClO3D computer program was developed by a team of experts in the Korean company "CLO Virtual Fashion Inc.". It was presented for the first time in 2009. It was created as a response to a more efficient and precise way of designing clothes. It enables the simulation of garments in virtual space before starting the manufacturing process. Over the years, CLO 3D has undergone dynamic development with frequent updates bringing new advanced cut and fabric simulation tools, improved user interface and integration with other software solutions.

CLO 3D enables the creation of digital clothing prototypes that can be viewed from all angles, i.e. in a 3D virtual space, while simulating the behavior of fabric in the real world. The program offers simulation of a certain design and its adjustment as much as necessary. Significantly reduces the time required for product development. It precisely simulates different fabrics, taking into account their texture, weight and stretchability.

Enables 3D visualization of garments. The program offers the possibility of creating customized avatar models and clothing items can be tested on different body types. Among the main advantages of CLO 3D is the reduction of production costs, which saves time and resources. The program also enables faster decision-making, as it has the possibility of quick changes and reviews. Simulations make it possible to accurately predict the behavior of the fabric, reducing the risk of errors in the later stages of production. Textile waste is also reduced due to fewer prototypes.

Clo3D also has some limitations. The high cost of the program can be a problem for smaller design houses or independent designers. The program also requires some time to learn, since it offers many advanced functions, and the optimal operation of the program requires good computers with advanced graphics cards, which can be an additional cost.

Clo3D is applied in various aspects of the fashion industry, including design, production, marketing and retail. Garment manufacturers can test how different fabrics affect the final product. Retailers also use 3D models to realistically display products in online stores, which can help consumers make decisions. CLO 3D has significantly improved the production process of making clothes because it enables fast realization of the design, reduces the time from concept to finished product. Simulation of clothes on virtual avatars allows for more precise tailoring and optimization of fabric selection (McQuillan, H., 2020)

In recent years, 3D clothing simulations have significantly improved the process of clothing production. The key is to create virtual prototypes as close as possible to the final appearance of the garment to minimize differences between the physical and virtual garment (Eurydice- Papachristou, E., Zolota-Tatsi, N.2024). For this, guidelines are needed that define the rules for creating virtual prototypes. The simulation system CLO 3D processes the virtual garment in detail. Virtual clothes are designed for digital spaces. 3D simulation tools offer many possibilities in choosing materials for making a garment. In the conventional method of making clothes, technical specifications define all aspects of production, including fabric, dimensions and construction method. To achieve consistency in 3D simulations, it is necessary to establish similar guidelines for virtual prototypes, Figure 1. (Makryniotis, T. (2015).

*a) placing pattern b) simulation c) render*

*Figure 1. Process 3D virtual garment creation in Clo3D*

Without these guidelines, the results of simulations can vary even though the same basic data such as avatars, cut parts and fabric are used. Creating production guidelines can be time-consuming, but it is crucial to achieving reliable and consistent results in simulations. Guidelines help standardize processes and allow rules to be set for simulation purposes. The guidelines need to be updated due to frequent upgrades of 3D simulation systems that regularly develop new functions and tools. Computer prototyping and simulation of the garment before the production process is very important for the fashion industry because it saves fabric that would be used for prototypes.

The above is important for the reduction of textile waste and for sustainable production, whether it is about making clothes according to the basic construction or the zero-waste concept method. In addition to reducing textile waste, computer simulation is good because the garment can be adjusted according to a certain body type and thus satisfy the criteria of fit and the aesthetic component, figure 2.

*Figure 2. Adaptation of clothing according to body type*

Fit limitations or the lack of aesthetic criteria of the initial design idea can be corrected before the production process, which ensures consumer acceptance of the garment. Clo3D is a clothing design program that allows the creation and modification of 3D garments, giving designers the opportunity to advance their ideas. It enables precise visualization of the fabric, cut and overall design of the garment. CLO 3D is used in the fashion industry for virtual design, production, fitting and presentation, improving conventional processes (Makryniotis, T. 2015)

## 3. ZERO WASTE

In the industrial processes of clothing production, there is still a lot of human labor that requires skilled hands, while fashion designers are often the least involved in the process of making a garment. Constructors and tailors often work separately from designers, requiring detailed technical drawing specifications to convey design ideas. The separation of designers, producers and consumers in the fashion system has led to large amounts of textile waste before and after consumption. Information about the amount of intercut losses often remains unknown to designers.

This problem can be partly solved by better cooperation between designers, constructors, manufacturers and consumers. In the context of sustainability, the cooperation of all participants in the fashion process is crucial in order to reduce textile waste and maintain aesthetic criteria in clothing design . Zero-waste design often requires additional adjustments due to the way the garment wraps around the body, so just as in industrial production, computer programs are used to aid in simulation to adapt the fit to the body prior to production.

Consumer feedback on the fit and comfort of clothing can provide a better understanding of design effectiveness towards a zero-waste concept. In the zero-waste concept, the fabric is used without intercut loss, and computer simulations further reduce the use of fabric for prototyping.
Many designers already use the Clo3D computer program extensively to develop two-dimensional tailoring parts, figure 3.

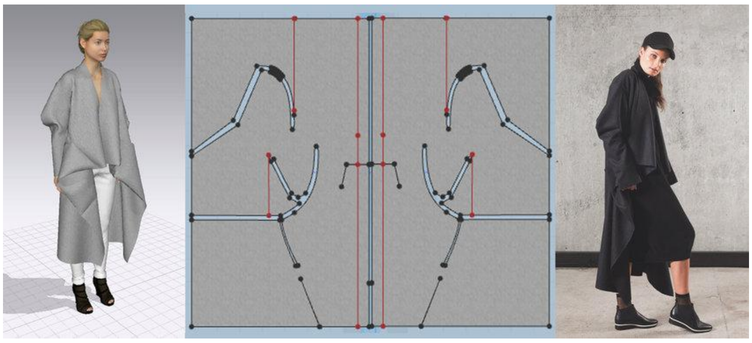

*Figure 3. The design process in the computer program CLO 3D*

The cut part is tested in dimensions that correspond to the body measurements of the avatar, which is most often in a certain selected clothing size. An important part of the design process is exploring the relationship between design and the body ( McQuillan, H., 2020).

## 4. CONCLUSION

The introduction of digitization as one of the elements of innovation in the teaching process is importance for students, which entails the entire process of transformation in the field of clothing production. This approach to the adoption of digital technologies finds its impact in reducing negative effects on the environment. A positive approach to clothing production is evident, which has an impact on inter-cut loss, which would be reduced to a minimum in this way. In this way, it is possible to reduce textile waste already in the production of clothing itself. Computer programs that allow designers and constructors to make quick changes in design and calculate intercut loss are certainly a positive change in clothing production. Textile technology students should learn to apply digital technology during their studies in order to improve the design and production processes of cuts and clothing after graduation, regardless of whether it is real or virtual clothing.

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# INTRODUCTION AND DISSEMINATION OF A PROPOSED STANDARD PROCEDURE FOR TESTING AND ORGANIZING PHYSICAL MATERIAL PROPERTIES OF TEXTILE FABRIC

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**ABSTRACT**

3D simulation is used in the textile industry for product design and product presentation alike. A fundamental requirement for a realistic simulation is the availability of physical material characteristics of the fabrics which are to be simulated. The manufacturers of the software products used to simulate clothing textiles have each developed proprietary test procedures and data formats for this purpose. These formats are not compatible with each other. This lack of standardization is a problem, as multiple different software solutions are usually employed within a value chain. The 3DRC is an initiative of users of textile simulation software from the clothing industry. It has proposed a new standard procedure for determining, processing and providing physical material data. This paper presents this standard approach, sets it in relation to similar approaches and discusses the suitability and feasibility of the proposed approach.

**Key words**: Simulation, Textile, 3D Material Physics, Conversion, Interoperability, Standardization

**INTRODUCTION**

Three-dimensional, realistic product visualizations (3D simulation) are state of the art in most industries. This applies equally to product design and engineering as it does to marketing and sales. In the area of design and engineering, computer aided design programs (CAD) can "increase operational efficiency, improve product quality, and gain a competitive advantage" [1] as they facilitate significantly faster and cheaper design iterations. The mechanical properties determine the soft-body – clothing interaction [2]. In the context of marketing and sales, 3D simulation gives e-commerce customers a better understanding of product dimensions and appearance, increases perceived product attractiveness and perceived product value , and can significantly increase customer confidence [3]–[6]. It also opens up new possibilities for product presentation, which can have a significant effect on advertising and marketing [3]. These can stimulate not only the search behavior, but also the communication and sharing behavior of customers [7]. These effects have also been researched and proven for online apparel retail. Virtual product presentation (VPP) and virtual fitting rooms (VFR) can increase sales and reduce returns [8]–[10].

In practice, the clothing and fashion industry sees great potential in the technology. 3D-CAD and simulation is a core aspect in the education of textile experts (see e.g. [11]). However, the industry faces a number of significant challenges in the use of 3D simulation. Not all of these challenges are directly linked to the use of the technology, but are of an organizational nature (e.g. fragmented company, no clear exchange of information, mistrust in new processes) [12]. Apart from these change management challenges, however, there are also challenges that are directly linked to the technology itself. One of the most significant challenges is the provision of real world (physics) data for the simulation.

## BACKGROUND

In the CAD programs, the designers create a 2D pattern and specify how the resulting pattern pieces are to be joined together. This information is used to obtain the 3D geometry of the garment for the simulation. In addition, however, information on the appearance (e.g. color, color pattern) and the physical properties (mass per unit area, elasticity, shear coefficient, etc.) of the fabric used is also required. At present, this data must be procured and provided by the user companies themselves.

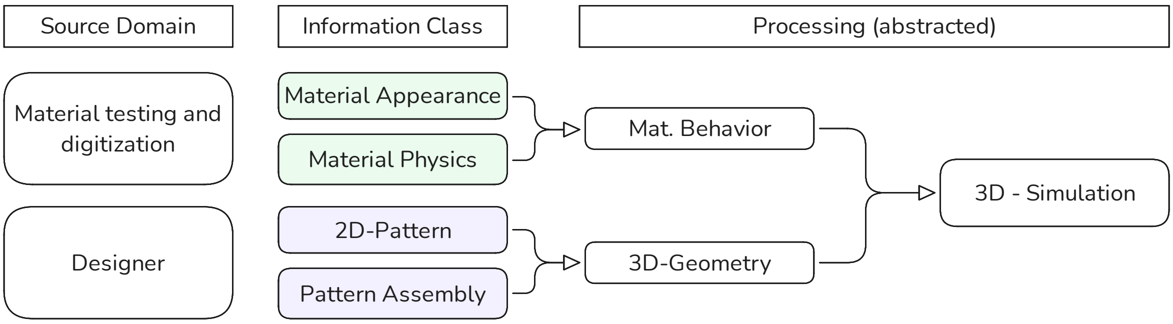


*Figure 1 Information Required for photorealistic 3D-Simulation of products made from textile fabric. Information which requires real-world testing is highlighted in green.*

### Appearance and Physics Data Procurement

Special scanning systems (e.g. Vizoo xTex [13], tg3d NunoX [14]) are available for recording information on the appearance of the fabric. The texture maps for rendering the fabric surface are output as raster graphics and can be loaded into the respective simulation program.

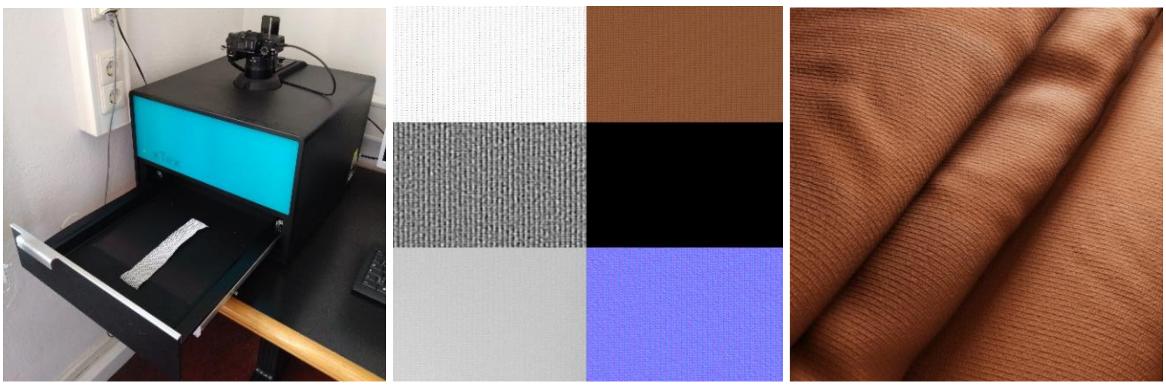

*Figure 2 From left to right: (1) Vizoo's xTex A4 - Device for Digitalizing Material Appereance. The fabric sample is placed in a drawer (opened in the picture), the drawer is closed and the fabic sample is photographed under various lightning conditions. (2) Resulting texture maps – alpha, basecolor, dispersion, metalness, normal map and roughness. (3) Photorealistic fabric rendering of the scanned fabric.*

Comparatively simple tests in accordance with various standards are also available for recording the physical properties of the fabrics (see Table 1). However, there is no standard for storing and exchanging this data. In fact, for every software ecosystem there is a proprietary way of measuring, evaluating and saving fabric physics data. Furthermore, there is no interoperability between these procedures: If a user company wishes to use multiple 3D-CAD software solutions, the fabric has to be tested separately for every ecosystem.

*Table 1 Comparison of textile-physical characteristics for the simulation of textiles, corresponding physical measurands and examples of corresponding standard test procedures.*

| **Characteristic** | **Corresponding physical measurands** | **Standard test procedure(s)** |
|---|---|---|
| Basis weight | Mass | DIN EN 12127 |
| Thickness | Distance at defined pressure | DIN EN ISO 5084 |
| Flexural rigidity (Bending) | Bending Moment or Overhang Length | DIN 53362 |
| Tensile strength (Stretch/Elongation) | Tensile force | DIN EN ISO 13934-1 |
| Shear force (Diagonal Stretch) | Tensile force in 45% direction or clamp response (picture frame) | DIN EN ISO 20337 |
| Springback behavior | Relationship between tensile force of consecutive tensile cycles | DIN 53835 |
| Friction | Pull Force (for static friction and sliding friction) | DIN EN ISO 8295 |
| Drapability | Projection of the sample or area/projection ratio | DIN EN ISO 9073-9 |

Between the different ecosystems, mass and thickness values are measured in comparable (and compatible) ways. The defining differences take place the procurement and processing of bending and especially elongation values.

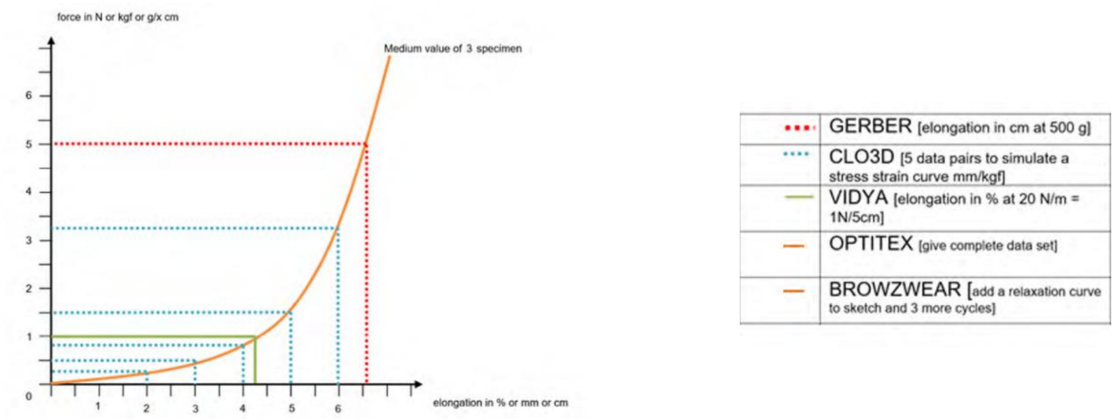


*Figure 3 Exemplary tensile curve with used data points according to 3D CAD manufacturers [15]*

## DIGITAL FABRIC INTEROPERABILITY PROJECT

The Digital Fabric Interoperability Project is a pre-competitive, industry-driven project of the 3D Retail Coalition (3DRC) [15]. The 3DRC is made up of brands, retailers and academics. The two objectives of the project are to recommend how fabric physics should be tested in a standardized way and to recommend how the data obtained can be transferred to the individual proprietary solutions [16]. Specifically, the software ecosystems of the 5 most relevant manufacturers were examined. The manufacturers of the individual software are not directly involved. The project and its results are therefore an example of a (collaborative) pull innovation (see e.g. [17], [18]).

### Approach

The 3DRC conducted expert interviews with the manufacturers ([19]–[24]) of the most relevant industry solutions to determine, which characteristics need to be accounted for in determining the material physics of a specific fabric or 3D simulation. These characteristics were then determined for 3 different fabrics, once using standard test methods and once using the respective proprietary solutions of the individual software manufacturers. This data was then used to determine and verify whether and how the data records for the individual software solutions can be obtained from the standard test data set. This procedure is shown in Figure 4.

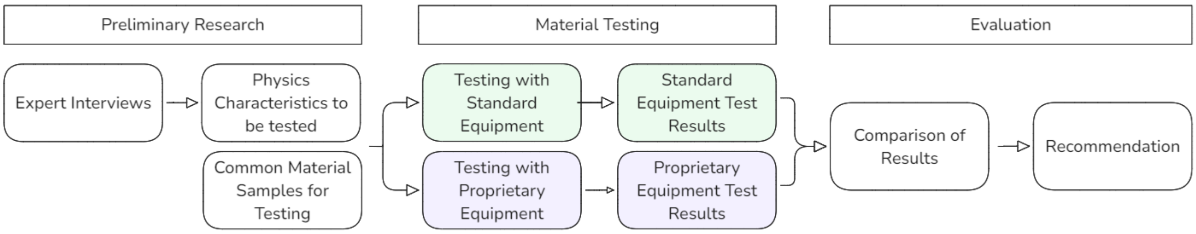


*Figure 4 Schematic representation of the procedure and phases in the Digital Fabric Interoperability Project*

**Findings**

The 3DRC concluded that the necessary material testing to determine the physics characteristics of fabric for 3D simulation can be done with standard testing equipment. Basic weight and thickness don’t require any conversion for the use between the examined programs. With one exception, the bending stiffness is also determined in the same way. The most significant differences are in the evaluation of the tensile and shear data. In principle, however, the same tests are carried out for flexural rigidity (bending) as well as for tensile strength and shear force. Only  also carries out cyclic tests when determining the tensile strength. [16] provides an overview of the manufacturers' test methods examined.

**Recommendations**

The 3DRC recommend the use of standard test methods and devices to determine the material characteristics and the subsequent conversion of the values for use in the individual programs. They recommend the use of standard test methods and devices to determine the material characteristics and the subsequent conversion of the values for use in the individual programs. They also advocate that the standard tests should be carried out by the fabric manufacturers or specialized laboratories and that this data should be made available to the clothing companies.

**3D Physics Conversion Tool**

To enable the calculation of the data sets for the 3D simulation in the individual CAD programs from the results of a standard check, the 3CRC provides not only the conversion formulas but also a web app *(“3D Physics Conversion Tool”*) [25] in which these formulas are implemented. In addition, another web app (“Calculation Tool”) [26] is also available to prepare data for use with the 3D Physics Conversion Tool. A screenshot of the main web app is shown in *Figure 5*.

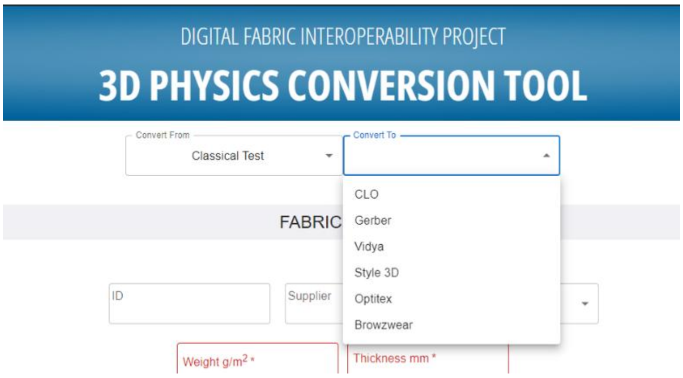


*Figure 5 Web App ("3D Physics Conversion Tool"), which is developed and made available by the 3DRC to convert the results of a classic textile test to the requirements of the individual programs.*

## RELATED WORK

[27] provide a similar commercial solution in the form of the physiX Conversion Tool, which can be used to convert the data sets of three of the programs examined by the 3DRC. This means that clothing companies only need to operate one of the proprietary test kits. [28] presents an overview of all the mechanical properties necessary for fabric simulation and propose a data structure for exchange.

## DISCUSSION

The 3DRC has proposed a standard operating procedure (SOP) for the determination of physical fabric characteristics, which differs considerably from the currently practiced procedure. Instead of the proprietary solutions of the individual software manufacturers, the 3DRC proposes the use of standard test procedures and devices and the subsequent conversion of the data according to the requirements of the programs.

This proposal implies that the proprietary testing devices and standard testing devices generate the same information. In principle, this is not unlikely. This assumption was investigated by the 3DRC with a rigorously designed experiment. However, the 3DRC has so far only used cotton fabrics for the verification of its method. Further investigations, especially with lightweight synthetic materials, are necessary for the verification of the process.

The 3DRC proposes the predominant use of standard test equipment. This is much more expensive to purchase and operate than the proprietary solutions of the individual software manufacturers. In addition, it must be operated by specially trained personnel. For most clothing companies, the development of this kind of infrastructure is unlikely to be economically viable. However, the 3DRC also proposes that in the future, the testing of materials will no longer be carried out by clothing companies, but will be borne by fabric manufacturers. It remains questionable whether these would make such an investment without industry-recognized standards for the nature of the procured data and its exchange. Instead, a solution within a value chain, which is jointly supported by the participating companies, would be conceivable.

The 3DRC explicitly proposes to outsource the testing of fabrics from the clothing companies. From an entrepreneurial point of view, this focus on the company's core activities makes sense. However, it should be noted that with this step, the company no longer builds up know-how in the testing of textiles. This know-how could possibly represent a strategic competitive advantage for the clothing company, which would also be eliminated accordingly.

Since the standard testing machines are more elaborately designed than the much cheaper proprietary testing machines of the software manufacturers, it can be assumed that they deliver better, more reproducible results in principle. The programs of the manufacturers only use a few data points for the simulation – especially of the displacement-force curves of the tensile and shear tests. The other values of the curve are not taken into account – and are not always stored. This represents a significant loss of information. For clothing companies, this loss of information is not sustainable, given the high cost of generating the information and the relatively low hypothetical cost of storing it. Rather it is perceivable that the currently unused datapoints of the curves could potentially be useful for the 3D simulation in the future. It is for example likely that in the future simulation methods will be used for 3D simulation that are far more advanced than the currently implemented methods. They may need more information than the currently implemented methods. They may also have a need for better (i.e. more accurate, higher resolution) information than the currently implemented methods.

## CONCLUSION

With their proposed SOP and their published "*3D Physics Conversion Tool*", he 3DRC has taken initiative towards a simplified, standardized way of procuring textile physics data for 3D simulation. At the moment, the SOP still requires further validation. However, it is an important step towards standardization of the generation and processing of material data for the simulation of textiles. The participation of many different companies in the project illustrates the relevance of this issue for the clothing industry. In the medium term, it is advisable (and likely) for the stakeholders concerned to agree on standards for the nature of the procured data and its exchange.

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# PATCHWORK IN FASHION: COMPARATIVE ANALYSIS OF PERCEPTIONS AND PREFERENCES BETWEEN FASHION DESIGN STUDENTS AND GENERAL CONSUMERS IN CHINA

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**ABSTRACT**

Patchwork techniques, rooted in the practical reuse of fabric scraps, have become a significant element of contemporary fashion, celebrated for their sustainability and aesthetic appeal. This study examines the differing perceptions and preferences for patchwork between fashion design students and general consumers in China. Using a mixed-methods approach, including surveys and interviews across nine major cities, the research reveals that fashion design students are more familiar with and appreciative of patchwork, viewing it as a platform for creative expression and sustainability. In contrast, general consumers recognize the aesthetic and sustainable benefits but are more concerned with practicality and cost. The study suggests that education plays a crucial role in shaping positive attitudes toward patchwork and that increasing consumer awareness, along with reducing production costs, could enhance the broader adoption of patchwork techniques in mainstream fashion. These insights offer valuable guidance for designers and marketers aiming to integrate sustainable practices into fashion.

**Key words**: patchwork techniques, fashion design, sustainability, consumer perception, market trends

## INTRODUCTION

Patchwork techniques have a long-standing history in textile arts, originating as a practical method for utilizing fabric scraps. Traditionally, patchwork was not only a means of resourcefulness but also a form of creative expression, reflecting the cultural heritage and aesthetic values of various communities [1,2]. In recent decades, these techniques have transcended their humble beginnings to become an integral part of contemporary fashion design, celebrated for their unique visual compositions and intricate craftsmanship.

The resurgence of patchwork in modern fashion can be attributed to several factors. Firstly, the growing awareness and demand for sustainable fashion have made patchwork an attractive option for designers and consumers alike. By emphasizing the reuse and recycling of materials, patchwork aligns with the broader movement towards eco-friendly and ethical fashion practices [3,4]. This focus on sustainability not only addresses environmental concerns but also resonates with a consumer base increasingly conscious of their ecological footprint. Secondly, the aesthetic appeal of patchwork is significant. The technique offers designers a versatile canvas to explore a multitude of textures, colors, and patterns. This versatility allows for the creation of highly individualized garments that stand out in a market often saturated with mass-produced items [5]. The ability to craft unique, statement pieces has made patchwork particularly popular in niche fashion markets and among consumers seeking to express their individuality through clothing.

However, the adoption and perception of patchwork techniques vary significantly among different consumer groups. Fashion design students, who are actively engaged in the study of textile arts and fashion trends, often view patchwork through the lens of innovation and artistic expression [6,7]. Their academic training provides them with a deeper understanding of the technical challenges and creative potential of these techniques. In contrast, general consumers may prioritize different aspects, such as the practicality and everyday wearability of patchwork garments. They might also have varying levels of familiarity with patchwork, influencing their appreciation and acceptance of such designs. While the uniqueness and sustainability of patchwork are appealing, practical challenges, such as the complexity of design and higher production costs, can pose significant barriers to widespread adoption. Additionally, there may be a disconnect between the creative aspirations of designers and the actual preferences of the broader consumer market.

This study explores the preferences and perceptions of patchwork techniques among fashion design students and general consumers. By examining differences in aesthetic appreciation, perceived benefits, and practical concerns, the research aims to provide insights into the integration of these techniques into both everyday and luxury fashion. The findings will contribute to a deeper understanding of the factors influencing the adoption of patchwork and offer practical recommendations for designers and marketers, ultimately supporting the sustainable fashion movement and the revitalization of traditional textile techniques in modern design.

## METHODOLOGY

### Research Design

Both quantitative surveys and qualitative interviews were employed in this study. This methodology was selected to provide a comprehensive overview of the topic, enabling the collection of quantifiable data alongside in-depth personal and professional insights into patchwork techniques in the Chinese fashion market.

### Data Collection

Surveys were administered to two distinct groups: fashion design students and general consumers across 9 representative Chinese cities with significant fashion markets and industries. These cities included Beijing, Shanghai, Guangzhou, Shenzhen, Hangzhou, Chengdu, Wuhan, Xi'an, and Nanjing. This selection ensured a diverse representation of regional fashion trends and consumer behaviors across China. The study received 237 valid responses from fashion design students and 206 from general consumers. Data collection spanned from September 2023 to July 2024, allowing for the capture of potential seasonal trends or attitude shifts over nearly a year. The surveys included questions designed to assess participants' familiarity with patchwork techniques, their aesthetic preferences, perceived benefits, challenges associated with these techniques, and their preferred garment categories for patchwork application. The questionnaire design underwent a pilot test to ensure clarity and reliability, followed by validation through expert review. In-depth interviews were conducted with 20 fashion industry experts, including designers, brand managers, and sustainable fashion advocates from various regions in China. These interviews aimed to gather professional perspectives on the practical applications of patchwork and to identify current market trends specific to the Chinese fashion industry.

### Data Analysis

The quantitative data collected from the surveys were analyzed using descriptive statistics to summarize the responses. To compare preferences and perceptions between the two groups, t-tests and chi-square tests were conducted using SPSS software, with significance levels set at $p < 0.05$. These statistical analyses helped identify significant differences and correlations in the data. The qualitative data from the interviews underwent thematic analysis. Two independent researchers coded the interview transcripts, identifying recurring themes and patterns. Subsequently, the researchers discussed and resolved any coding discrepancies to ensure the reliability of the analysis.

## RESULTS

The demographic characteristics of the survey participants are shown in Table 1. The study included 237 fashion design students and 206 general consumers from 9 representative Chinese cities.

*Table 1: Demographic information of survey participants*

| Group | Number of Participants | Average Age (SD) | Gender Distribution |
|---|---|---|---|
| Fashion Design Students | 237 | 23 (±2.1) | 82% Female, 18% Male |
| General Consumers | 206 | 34 (±5.3) | 58% Female, 42% Male |

### Familiarity with Patchwork Techniques

Table 2 indicates the level of familiarity with patchwork techniques among the participants. A significant 59% of fashion design students reported being very familiar with these techniques, compared to 38% of general consumers. Notably, 25% of general consumers were not familiar with patchwork, highlighting a potential gap in consumer knowledge.

*Table 2: Familiarity with patchwork techniques*

| Group | Very Familiar (%) | Somewhat Familiar (%) | Not Familiar (%) |
|---|---|---|---|
| Fashion Design Students | 59% (±3.1), CI [52.9%, 65.1%] | 32% (±3.0), CI [26.1%, 37.9%] | 9% (±1.8), CI [5.5%, 12.5%] |
| General Consumers | 38% (±3.3), CI [31.5%, 44.5%] | 37% (±3.3), CI [30.5%, 43.5%] | 25% (±3.0), CI [19.1%, 30.9%] |

Chi-square test results showed a significant difference in familiarity with patchwork techniques between the two groups ($\chi2 = 42.67$, $df = 2$, $p < 0.001$).

### Preferences for Patchwork in Fashion Design

As presented in Table 3, preferences for patchwork designs varied between the two groups. While 49% of fashion design students highly preferred patchwork designs, only 29% of general consumers expressed the same level of enthusiasm. However, 46% of general consumers somewhat preferred these designs, showing a broader acceptance.

*Table 3: Preferences for patchwork in dashion Design*

| Group | Highly Prefer (%) | Somewhat Prefer (%) | Neutral (%) | Do Not Prefer (%) |
|---|---|---|---|---|
| Fashion Design Students | 49% (±3.2), CI [42.7%, 55.3%] | 35% (±3.1), CI [28.9%, 41.1%] | 12% (±2.1), CI [7.9%, 16.1%] | 4% (±1.3), CI [1.5%, 6.5%] |
| General Consumers | 29% (±3.1), CI [22.9%, 35.1%] | 46% (±3.4), CI [39.3%, 52.7%] | 17% (±2.6), CI [11.9%, 22.1%] | 8% (±1.9), CI [4.3%, 11.7%] |

T-test results indicated that fashion design students had a significantly higher preference for patchwork designs compared to general consumers ($t = 6.18$, $df = 441$, $p < 0.001$).

### Perceived Benefits of Patchwork Designs

The perceived benefits of patchwork designs varied among the groups, as detailed in Table 4. The unique aesthetic appeal was recognized by 75% of fashion design students and 64% of general consumers. Sustainability was highly valued by both groups, with a greater emphasis from fashion design students (68%). In contrast, general consumers placed more importance on cultural significance (39%) and cost-effectiveness (35%).

*Table 4: Perceived Benefits of Patchwork Designs*

| Perceived Benefit | Fashion Design Students (%) | General Consumers (%) |
|---|---|---|
| Unique Aesthetic | 75% (±2.8), CI [69.5%, 80.5%] | 64% (±3.3), CI [57.5%, 70.5%] |
| Sustainability | 68% (±3.0), CI [62.1%, 73.9%] | 52% (±3.4), CI [45.3%, 58.7%] |
| Cultural Significance | 45% (±3.2), CI [38.7%, 51.3%] | 39% (±3.4), CI [32.3%, 45.7%] |
| Cost-Effectiveness | 30% (±3.0), CI [24.1%, 35.9%] | 35% (±3.3), CI [28.5%, 41.5%] |

**Preferred Garment Categories for Patchwork Application**

Table 5 shows the preferred garment categories for the application of patchwork techniques. A significant majority of fashion design students (78%) preferred applying patchwork to jackets and coats, followed by dresses (65%) and T-shirts and tops (56%). General consumers showed a similar pattern but with slightly less enthusiasm across all categories.

*Table 5: Preferred garment categories for patchwork application*

| Garment Category | Fashion Design Students (%) | General Consumers (%) |
|---|---|---|
| Jackets and Coats | 78% (±2.7), CI [72.7%, 83.3%] | 55% (±3.4), CI [48.3%, 61.7%] |
| Dresses | 65% (±3.1), CI [58.9%, 71.1%] | 50% (±3.4), CI [43.3%, 56.7%] |
| T-shirts and Tops | 56% (±3.2), CI [49.7%, 62.3%] | 42% (±3.4), CI [35.3%, 48.7%] |
| Skirts | 51% (±3.2), CI [44.7%, 57.3%] | 37% (±3.3), CI [30.5%, 43.5%] |
| Pants and Trousers | 45% (±3.2), CI [38.7%, 51.3%] | 34% (±3.3), CI [27.5%, 40.5%] |
| Accessories (Bags, etc.) | 39% (±3.2), CI [32.7%, 45.3%] | 28% (±3.1), CI [21.9%, 34.1%] |

**ANALYSIS**

The demographic analysis reveals distinct differences between fashion design students and general consumers in terms of their backgrounds, perspectives, and familiarity with patchwork techniques. Fashion design students, with an average age of 23 and a gender distribution of 82% female and 18% male, are generally more immersed in environments that encourage creativity, innovation, and exploration of various fashion techniques, including patchwork. This immersion is reflected in their higher levels of familiarity and preference for patchwork, as shown by the significant results of the chi-square test ($\chi 2 = 42.67$, $p < 0.001$) and the t-test ($t = 6.18$, $p < 0.001$). These results suggest that formal education and exposure to textile arts significantly enhance the understanding and appreciation of patchwork's artistic and technical complexities.

To further explore the differences in perceived benefits and garment category preferences, additional statistical tests were conducted. T-tests on the perceived benefits (Table 4) reveal that fashion design students have a significantly stronger appreciation for the unique aesthetic and sustainability of patchwork designs compared to general consumers ($p < 0.05$). However, no significant differences were observed between the groups in their views on cultural significance and cost-effectiveness, indicating a shared perspective in these areas.

Similarly, chi-square tests on garment category preferences (Table 5) indicate significant differences in preferences for jackets and coats ($p < 0.05$), with fashion design students showing a stronger preference for these items compared to general consumers. Other categories, while showing differences, did not reach statistical significance, suggesting that while fashion design students are more open to using patchwork in a wider range of garments, the general consumer market remains more selective.

These findings highlight that while fashion design students are more inclined to embrace the artistic and sustainable aspects of patchwork, general consumers are more pragmatic, with concerns focused on practicality, cost, and mainstream appeal.

## CONCLUSION

The study highlights a generally positive attitude toward patchwork techniques in fashion design, particularly among fashion design students, who are more inclined to appreciate the artistic and sustainable qualities of these techniques. The significant differences in familiarity and preferences between fashion design students and general consumers underscore the impact of education and exposure on the appreciation of specialized fashion techniques. Fashion design students tend to favor the creative and innovative aspects of patchwork, seeing it as an opportunity to produce unique and environmentally sustainable garments. However, general consumers approach patchwork with more caution, focusing on practical considerations such as cost, wearability, and the mainstream appeal of these designs. The statistical analysis further reveals that the differences in perceived benefits and garment category preferences are significant in some areas, particularly in the appreciation of the unique aesthetic and sustainability of patchwork, as well as preferences for jackets and coats. However, similarities in views on cultural significance and cost-effectiveness indicate areas of common ground between the two groups.

To enhance the adoption of patchwork techniques among general consumers, it may be necessary to increase consumer education about the versatility and practicality of patchwork garments. Highlighting the durability, uniqueness, and sustainability of these garments through targeted marketing strategies could help demystify patchwork and make it more appealing for everyday use. Additionally, exploring technological advancements that could reduce the production costs of patchwork garments could make these unique pieces more affordable and accessible to a broader audience.

Future research should consider exploring the cultural influences that shape the acceptance of patchwork, as well as regional differences in consumer behavior. Understanding these nuances could provide valuable insights for designers and marketers aiming to integrate patchwork into both high fashion and mainstream markets. By addressing the challenges identified in this study and capitalizing on the growing interest in sustainable fashion, patchwork techniques could become a more prominent feature in the fashion industry, offering consumers a stylish and eco-friendly alternative in their wardrobes.

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# DEVELOPMENT OF AN OPEN FORMAT FOR THE EXCHANGE OF 3D GARMENTS BETWEEN 3D PRODUCT DEVELOPMENT SOFTWARE PACKAGES

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## ABSTRACT

The open formats dxf-AAMA and dxf-ASTM facilitate the data exchange of 2D cutting patterns, but there is currently no open format available for the exchange of 3D cutting patterns. Many software providers offer 3D product development formats. However, these formats are typically locked and exchange between platforms is either not available, or tedious and erroneous. As the clothing and textile industry is currently experiencing a great leap toward digitization and automation, the availability of an open file format for the exchange of 3D cutting patterns is imperative.
In this paper, an open format for the exchange of 3D cutting patterns is proposed and documented. The developed file format is designed to be added onto the dxf-ASTM file of the respective 2D cutting pattern. Pieces from the dxf-ASTM file are referenced in the proposed format, and affiliations, seam types and stitches included in the product design listed and referenced. Currently not included are material specifics, such as the material characteristics or haptics.
The file format is documented both in this paper and openly accessible and documented on common software development platforms such as GitHub.

**Key words**: 3D garments, file format, data exchange, dxf-ASTM, virtual product development

## INTRODUCTION

The digitalisation of the apparel industry and development has already been reinforced by the emergence of e-commerce. The COVID-19 pandemic and associated changes in supply chains and workflows have been a catalyst for the shift to fully digital collections and a move away from physical samples [1, 2, 3]. Not only does this reduce the cost of preparing and assembling garments and collections, moving away from physical samples is more resource efficient and sustainable [4]. However, there are still challenges in the digital development of textile products, such as the differences in functionality and simulation results between different programs and platforms [5]. To simplify the transfer and exchange of patterns and the work with different programs for different purposes, a standardised data format was introduced, first dxf-AAMA and then dxf-ASTM [6]. However, garment references, seams and stitches are included in neither dxf-AAMA nor dxf-ASTM [6]. 3D cutting patterns and garment models are saved and exchanged using the software providers native formats, which are usually locked and typically cannot be opened in other providers software packages or programs. Yet, as brands and manufacturers thrive towards fully digital product development and collections, and are using different providers software, the need for a universal exchange format of 3D cutting patterns and garment models arises.

In this paper, first cutting patterns and their information content are defined. Following, the existing standardized file format dxf-AAMA and dxf-ASTM are briefly introduced. The requirements for a file format standard for 3D cutting patterns are compiled and the file format development explained. The developed format is then tested on the example of a T-shirt (reduced to seams between front and left sleeve as well as back and left sleeve for the sake of conciseness). Concluding, the requirements and developed format are summarized and an outlook for both possible extensions and implementation provided.

## EXISTING FILE FORMATS

All CAD tools for the design of textile products such as apparel process the same dimensions, shapes, and additional information, but store them in different formats and structures, with varying levels of information depth [6]. Because of these differences in the storage of congruent content, the secure exchange of information between different platforms and development environments remains a challenge. A complete 2D cutting pattern contains the designation of the garment, the outline of each piece of the garment in a set of clothing sizes, i.e. grading, seam allowances or directions regarding them, thread run and notches [7].

Every software provider uses a native format to save developed cutting patterns and there are two supplemental open formats, which are designed to be a standard for cutting pattern exchange between different platforms and points along the value chain. The first standard to be published was dxf-AAMA, a dxf-based open standard. However, the information content of dxf-AAMA is relatively limited, not including, e.g. reference and mirror lines, pattern references or sewing lines [6]. Thus, the dxf-AAMA standard was extended to the dxf-ASTM. Also based on the dxf-file format, the dxf-ASTM standard had a considerably greater information content, enabling users to save complete cutting pattern that can be further used for both cutting and continuing product development [7].

The format dxf-ASTM is a fitting standard for saving and exchanging cutting pattern information, but the requirements for information exchange have increased in recent years. In the current thrive towards full digitization and fully digital collection development, it is not further sufficient to exchange 2D cutting patterns. Especially in product development, it is further vital to exchange the product assembly, including seams, seam types, seam overlaps, stitch types, buttons, buttonholes and iron lines. There are many closed native formats for this type of 3D cutting pattern. However, those cannot necessarily be used for cross platform file exchange.

Thus, the need for a 3D cutting pattern file format for cross-platform is a pressing issue to further digitize product development and aid communication between designers, brands and manufacturers.

## FORMAT DEVELOPMENT

The representation of an entirely assembled garment requires details about pieces including names, boundaries, internal cutouts, internal lines and holes given by 2D cutting patterns. Furthermore, information about seams, stitches, iron lines and hardware along with their associations to given pieces at certain coordinates is required. The new 3D cutting pattern format must therefore incorporate geometric data from the 2D cutting pattern of the respective product, as provided in a dxf-ASTM file. Seams, stitches, iron lines and hardware must be listed and referenced to the 2D geometries of the pieces.

There are two options for developing the new format. Firstly, the dxf-ASTM format can be extended to include information on seams, stitches, iron lines and accessories. This would allow using and extending an existing file structure, and saving all necessary information in one file, but the new format would not be integrated in existing software packages. None of the information could be accessed using existing software packages once saved in this format. Further, placeholders for material characteristics of the textile material(s) would be necessary to be used in fit and garment simulations during the virtual product development.

The second option is to develop an unlocked format that is added onto dxf-ASTM. Using a separate add-on file would enable opening and editing the 2D cutting pattern in the current ASTM standard as needed without integration of the 3D format in the respective software package. This is especially helpful during transitions, where some software packages are outfitted with an importer, while others are not. Further, the material characteristic could also be saved separately using the open U3M file format by Vizoo GmbH [8]. Pattern, affiliations and material characteristic could be saved, edited and reused independently.

The add-on format can be constructed using the structure elements of, for example, the Extended Markup Language (xml) or the Java Script Object Notation (json). As json enables extensive structuring of data due to working with indentations, lists or encapsulated objects, and dxf and xml do not offer the same functionality, json was chosen for developing the add-on format. A json-file is easy to read and facilitates clear structuring of the data with flexibly definable properties. The value of an object's property can be a classic data type such as string, number or boolean, a list or again an object with its own properties. Thus, the data structure can be scaled in depth as required while maintaining clarity. The json-structure developed for storing the data of a 3D cutting pattern is presented below.

The developed format has the respective 3D cutting pattern as basic object containing several lists for parts, stitches and seams as well as an object for units as properties. Units for technical quantities in the file such as stitch density or thread tension are defined in the *units* object. There is one property for each technical quantity in the object with the corresponding unit assigned as property value. The basic structure of the 3D cutting pattern format is shown in Figure 6.

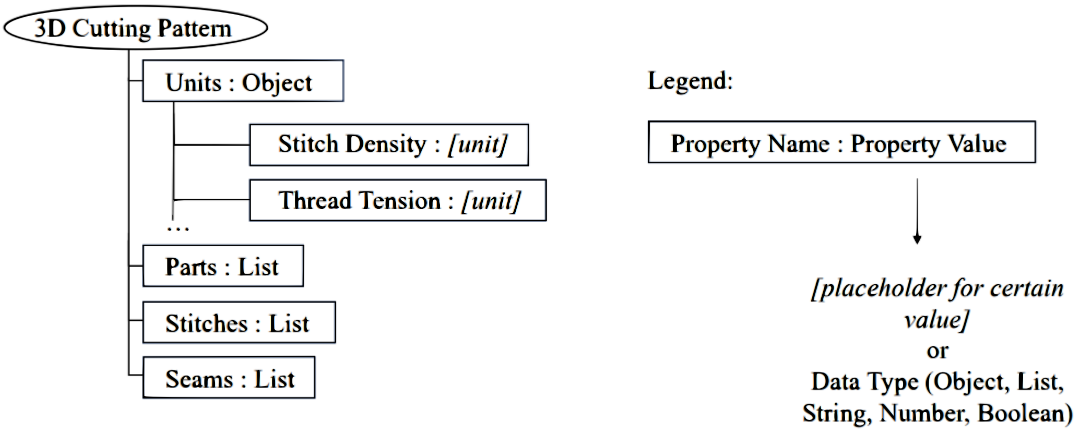


*Figure 6: Basic json-structure of 3D cutting pattern format*

A part in the list of parts is represented by an object, being structured according to the json-structure in Figure 2. Each individual part is uniquely identified by an ID. The ID contains the name of the part from the dxf-ASTM file, which facilitates a reference to the geometric details of the part in the dxf-ASTM file. Each part has assigned lists for edges and internal lines. One item in one of these lists corresponds to an object with a unique ID for the edge or the internal line respectively and with coordinates from the dxf-ASTM file. The coordinates indicate the end points of the defined edge or internal line, which allows them to be clearly recognised in the geometry of the part.

All sewing line of the textile product are listed as separate objects in the list of stitches. A sewing line object corresponds to a continuous sewing operation without intermediate cutting of the sewing thread and is labelled with an ID. Further properties of a stitch object correspond to the parameters stitch type and stitch density. The stitch type is clearly indicated by the respective number in the ISO 4915 standard. A list of threads is also an assigned property and contains a number of thread objects depending on the stitch type. A thread object in this list has the properties thickness, yarn count, material and tension. The explained structure for stitches is illustrated in Figure 3.

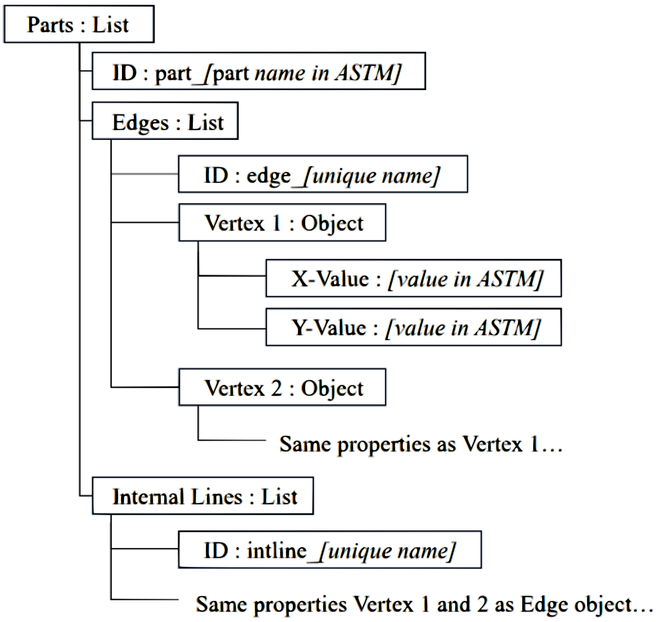


*Figure 2: Json-structure of part object*

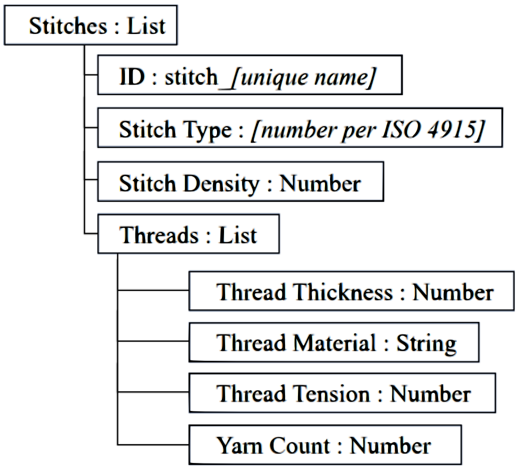


*Figure 3: Json-structure of stitch object*

The list of seams contains the seams of the product as objects, each with an ID. A seam object represents a seam with a unique configuration of seam type, sewn edges or internal lines of parts in a specific layer on top of each other as well as applied stitches. The seam type property is clearly identified by its number in ISO standard 4916. Sewn edges and internal lines of parts are enumerated in a list of the seam object in a defined sequence with their IDs indicating the affiliation to respective part objects. The order of the edges and internal lines in the list corresponds to their order from top to bottom viewing the seam image of the seam type in the ISO standard 4916 (see Figure 4, *Edge 1* is listed before *Edge 2*). In a further list of the seam object, the assigned stitch objects are referenced by their IDs and listed in a defined order. The order of the stitches in the list corresponds to their order from left to right in the seam image (*Stitch 1* is listed before *Stitch 2*). Furthermore, the required sewing direction is also specified for each stitch. The value *Top Down* indicates that the needle is to be moved from the top of the seam, according to ISO 4916, *Down Top* refers to the opposite case. If value *Both* is assigned, the direction can be freely chosen.

Considering the previously mentioned properties of a seam object, there is still information about the proper alignment of parts in the seam left to be defined. One example is shown in Figure 5, where the seam between the front part and one sleeve of a shirt could be stitched in two different ways. The first way corresponds to laying vertex 2 of edge 1 on top of vertex 1 of edge 2 in the manner of the desired seam type and thus vertex 1 of edge 1 on top of vertex 2 of edge 2. The second way refers to the opposite combinations of vertices of the edges. In Figure 5, the first way is the feasible one, which is to be captured in the seam objects properties. Therefore, a seam object has two properties corresponding to the endpoints of the respective seam. Each endpoint is assigned a list of vertices with the vertices being enumerated in the order according to their corresponding edges order in the list of edges and internal lines. A vertex object in the list of vertices has one property with a value of 1 or 2 indicating which of both vertices of the respective edge or internal line is assigned to the endpoint. All vertices being determined to be put on top of each other are assigned to the same endpoint to clarify the alignment of edges in the seam. A further property of an endpoint is its ID. If two seams have endpoint objects with the same ID, it is an indication for the seams to be in contact with each other.

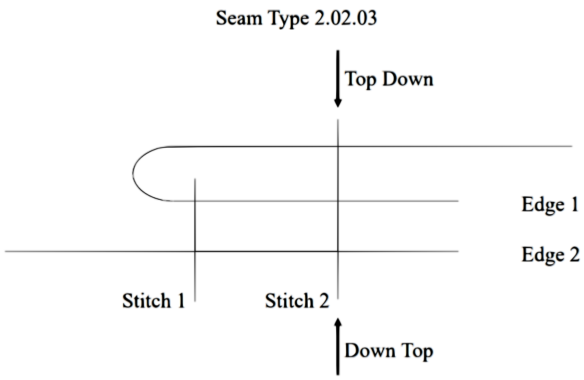


*Figure 4: Seam image of seam type 2.02.03*

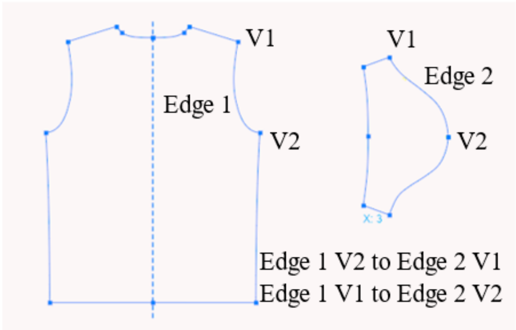


*Figure 5: Edge alignment between front and sleeve*

The explained structure of a seam object is shown in Figure 6. A seam object with mentioned properties facilitates the clear definition of joining seams, darts, hems as well as ornamental seams. Several seam objects can be assigned the same stitch object, as a stitch can be applied to fasten a number of seams in a row. An edge or internal line of a part is always related with only one seam.

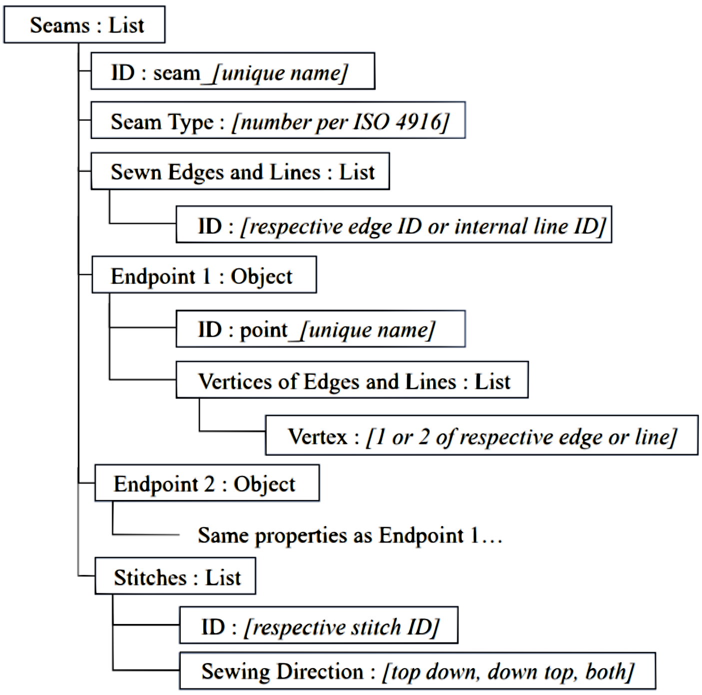


*Figure 6: Json-structure of seam object*

## EXAMPLARY FILE

To demonstrate, the developed format is applied to the example of a T-shirt. For the sake of conciseness, the instance is limited to the seams between the front and left sleeve as well as the back and left sleeve. Figure 7 displays the text base of the corresponding json-file. Objects are listed in a reduced version, thus some of the previously mentioned properties are not displayed. In the list of parts, the three parts are enumerated as objects including certain edges. Two separate edges (*edge_2* and *edge_3*) are defined for the left sleeve (*part_leftArm*), as these are sewn in different seams and therefore the coordinates of the end points of both edges are required. Furthermore, a stitch with stitch type is defined. A seam object is introduced for each of the two seams, with the seam types and the fastening stitch being identical. For visual reasons, the seam between the front and sleeve and between the back and sleeve should be sewn in one continuous operation and therefore the same stitch object is assigned to both seam objects. The stitch can be executed both when the edges of the sleeve lay under the edges of the front and back and vice versa. Thus, the sewing direction is *Both*. In the seam object between the sleeve and the front (*seam_1*), the vertices are assigned to the end points of the seam for the correct alignment of the parts as shown in Figure 5. Furthermore, the two seams touch at the two points, where the front, back and sleeve contact each other, indicated by equal point IDs (*point_1* and *point_2*) in both seams.

```
{   "parts": [  {   "id": "part_front",
                    "edges": [  {   "id": "edge_1",
                                    "vertex1": {    "x": 20.5,
                                                    "y": 15.7},
                                    "vertex2": {}}]},
                {   "id": "part_leftArm",
                    "edges": [  {   "id": "edge_2",
                                    "vertex1": {},
                                    "vertex2": {}},
                                {   "id": "edge_3"}]},
                {   "id": "part_back",
                    "edges": [  {   "id": "edge_4"}]}],
    "stitches": [   {   "id": "stitch_1",
                        "stitchType": "301"}],
    "seams": [  {   "id": "seam_1",
                    "seamType": "1.01.01",
                    "sewnEdges": [  {   "id": "edge_1"},
                                    {   "id": "edge_2"}],
                    "endPoint1": [  {   "id": "point_1",
                                        "vertices": [   {   "vertex": 2},
                                                        {   "vertex": 1}]}],
                    "endPoint2": [  {   "id": "point_2",
                                        "vertices": [   {   "vertex": 1},
                                                        {   "vertex": 2}]}],
                    "stitches": [   {   "id": "stitch_1",
                                        "stitchDirection": "both"}]},
                {   "id": "seam_2",
                    "seamType": "1.01.01",
                    "sewnEdges": [  {   "id": "edge_4"},
                                    {   "id": "edge_3"}],
                    "endPoint1": [  {   "id": "point_2"}],
                    "endPoint2": [  {   "id": "point_1"}],
                    "stitches": [   {   "id": "stitch_1",
                                        "stitchDirection": "both"}]}]}
```

*Figure 7: Exemplary file for two seams of a T-shirt*

The developed format facilitates the representation of 3D cutting pattern including parts, stitches and seams based on 2D cutting pattern data in dxf-ASTM. Further features like iron lines, buttonholes and hardware are not included as of now.

## SUMMARY

In this paper, an open access file format for the transfer of 3D cutting patterns, including sewing lines, affiliations and stitch types is proposed.

As the existing standardised file formats for cutting pattern transfer between platforms, dxf-AAMA and dxf-ASTM, are suitable for the transferring cut and pattern information but not affiliations, seams, seam types, and stitch types, there is currently no standardised way to transfer 3D cutting patterns. The proposed file format is a json-based extension of dxf-ASTM, which references pieces and edges and contains affiliations, seam types, stitch types and sewing direction. Thus, the 2D cutting pattern is independent of the assembly information and can be viewed and altered independently.

The file format as introduced is currently limited to assembly-relevant information, but the json-structure allows further integration of hardware, iron lines, buttonholes etc. Material characteristics, necessary for fit and garment simulations can be integrated using the open access U3M file format.

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# AI & INDUSTRY 4.0 SUPPORTED FASHION DESIGN – A CASE STUDY OF A SUSTAINABLE DENIM COLLECTION

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**ABSTRACT**

The fashion industry, a realm of creativity and innovation, has long grappled with the weight of environmental responsibility. The advent of artificial intelligence (AI) has ushered in a new era for sustainable fashion design, presenting a vast array of opportunities. This is particularly significant in sectors with intricate manufacturing processes, such as denim, where AI can significantly reduce waste and enhance sustainability.
AI fundamentally transforms how designers approach product development, material procurement, and waste reduction. It enables the creation of digital prototypes and virtual garments, significantly reducing the need for physical samples and playing a crucial role in waste reduction. This conserves resources and diminishes the carbon footprint associated with traditional sample production. By integrating artificial intelligence into the design process, designers can experiment with materials and designs in a virtual environment, reducing waste and promoting sustainability.
This article explores how AI and Industry 4.0 technologies support and shape the future of fashion design. By integrating various advanced tools into the design and pre-production process, AI is creating a more sustainable future for the industry. This case study of the creation and realisation process of an autonomous denim collection is a testament to the industry's optimistic and reassuring direction.

**Keywords:** AI, Artificial Intelligence, Industry 4.0, Engineering, Sustainable Fashion, Fashion

## AI & THE FASHION INDUSTRY

Artificial Intelligence (AI) is rapidly reshaping the fashion industry landscape, introducing innovations that streamline production, enhance creativity, and address sustainability challenges. AI's ability to analyse and predict trends has become a game-changer in fashion. [1] As a result, companies can design and release collections that are more aligned with consumer preferences. Personalisation, a key feature of AI, significantly reduces returns and unsold inventory, promoting sustainability in the fashion industry. AI optimises supply chains, reduces waste, and promotes sustainable practices. [2]

AI significantly optimises design, pattern creation, and sample manufacturing. Integrated into Industry 4.0 systems, AI automates fabric cutting and quality control, speeding up production and reducing costs. It also helps designers create collections, avoid overproduction of samples, and promote sustainability. AI is a valuable tool for designers. It inspires by analysing trends, historical styles, and consumer preferences to generate new concepts. By collaborating with AI, designers can create innovative collections that align with trends while expanding creative possibilities.

AI is critical in promoting sustainability in fashion design by optimising supply chains and reducing waste. It improves inventory management, predicts demand more accurately, and minimises unsold items. Additionally, AI enhances personalisation, offering tailored clothing recommendations that reduce returns and further cut waste, making the design process more sustainable. [3]

**The Fusion of AI and Fashion Design**

AI algorithms are transforming how fashion designers approach creativity, harnessing the power of vast datasets to generate innovative patterns and designs. AI-driven tools are helping brands deliver cutting-edge fashion that resonates with their target audience. [4] [5] [6] [7] In summary:

- AI enhances inclusivity by accommodating various body types and styles.
- AI facilitates real-time feedback and customisation during the design process.
- AI-driven simulations streamline the design of unique creations.

## AI IN DENIM DESIGN

AI is becoming essential in denim design, offering innovative solutions in an industry that blends tradition with modern trends. As denim continually evolves, AI equips designers with tools to enhance creativity while preserving its iconic status. AI optimises fabric treatments, washes, and generates unique patterns and fits, enabling faster design iterations and personalised styles. It also boosts sustainability by improving manufacturing efficiency, accurately predicting demand, and reducing waste. AI drives creativity and sustainability in a competitive market, helping brands meet consumer demands for innovation and eco-friendly practices. Additionally, AI is a powerful tool for executing unique art projects.

**The project IKONIKA SELVEDGIKA: Sustainability and AI in Denim Design**

The art project IKONIKA SELVEDGIKA has been submitted for the call of The Cultural Foundation for the Textile Arts and the SAVARIA MUSEUM – SZOMBATHELY GALLERY that organised the VIII—International Triennial of Textile Arts at the Szombathely Gallery between 21 June 2024 and 31 August 2024. The designs for the project have been realised by using the pro version of the software Midjourney Bot Discord v 6.0 for the creation of the design of the outfits. Figures mark the beginning of experimentation for the art project, illustrating how continuous re-evaluation and selection of the most accurate results lead to refined variations and a more precise approach to the concept. The series of designs below were created using /imagine [prompt]: *"I see raw denim dresses, with wide hems, contoured cut lines"*. (Fig 1)

*Figure 1: Variations on a raw denim dress. Copyright 2023 AI experiments by edit@** Software: Midjourney Bot Discord v 6.0*

By fine-tuning AI commands, the designer corresponded to her initial expectations and generated designs with clear boundary lines, selvedges, and turn-ups. Fine-tuning the command resulted in original creations. Figure 2 shows the series of designs submitted for the call.

*Figure 2: Variations on raw denim dresses. Copyright 2023 AI experiments by edit@***

This process allowed for more innovative, eco-friendly denim designs that pushed fashion's creative and technological limits. The figure shows two of the final designs selected by the jury of the Triennial: (left) dress AISHA, and (right) jacket AICHI and skirt AIMOTO. The pictures show the final images of the outfits authentically. This makes decision-making easier when choosing the best outfit designs. (Fig 3)


*Figure 3: Variations on raw denim dress. Copyright 2023 AI experiments by edit@***

**METHODOLOGY OF REALISATION OF THE OUTFITS**

Incorporating Artificial Intelligence into the creative process introduced new opportunities, but we also met new challenges. The methodology of the execution of the outfits presupposed a completely new method, given that the execution takes place in reverse order, in which the goal is to achieve the expected overall image, including all details of the overall aesthetics (quality of raw materials, proportions, construction, details, etc.) The process started with the preparation of the designer's master sheet, during the preparation of which the construction and proportions of the outfit shown in the picture, as well as its production technology, were "reconstructed". This process makes collection design significantly more cost-effective and sustainable, promising new challenges. Both the designer and the modellers have to reconstruct the outfits shown in the lifelike images from the point of view of construction and production technology, for which a high level of professional knowledge is essential.

The methodology for modelling and sewing the samples will be introduced using the example of the realisation of the outfit formed by the AICHI top and AIMOTO skirt.

**Modelling process of the AICHI top and AIMOTO skirt**

Based on the drawings received from the designer, the pattern makers primarily looked at the proportions shown in the images of the outfit and the detailed design worksheets received, including the detailed technical drawings (fashion flats) that were necessary to explain the details of the garment dreamed up by the designer. (Fig 4) The basis of production preparation is a drawing that the modeller and the contractor can read. [8] The designer asked for the prototype to be made in size 36. Morgan Tecninca's CAD program was used for the modelling process. [9]

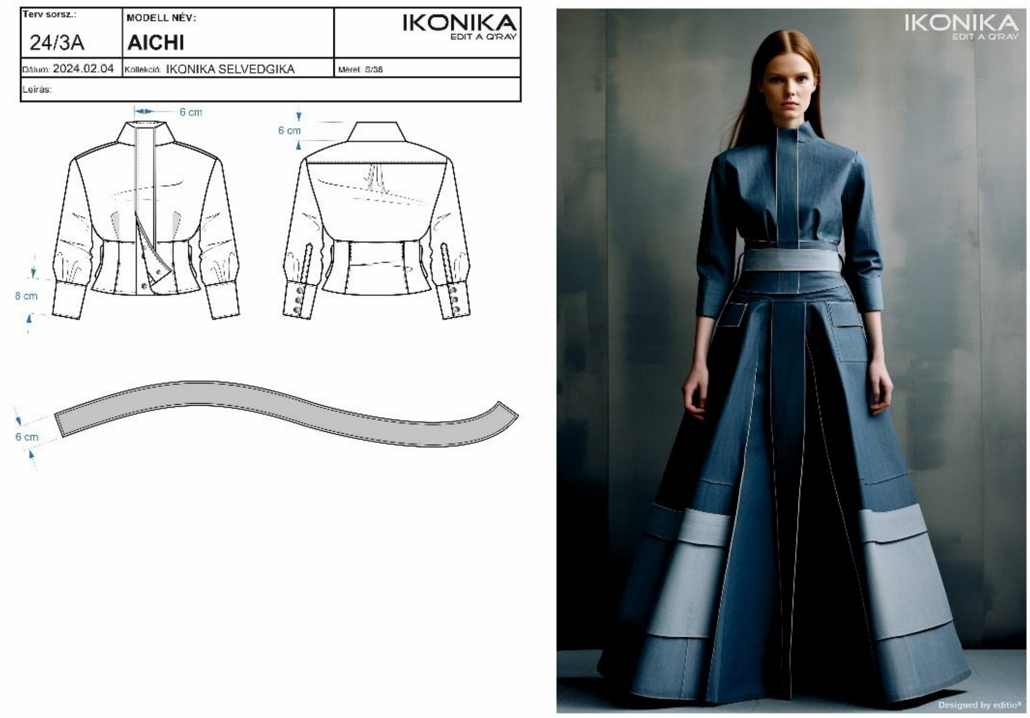


*Figure 4: The AICHI's top design worksheet*

**The design of AICHI's top cut patterns**

The work started with a serialised blouse basic design to create the AICHI top. (See Fig 5)
The basic pattern for the top included a 4 cm extra comfort on the bust, and this abundance was used in the design of the model's pattern. Under the bust, the waist part has been transformed into a corset shape. The sewn-in sleeves are ¾ length, the bottom ends in a cuff and closes with three snaps. The seam width on the tailoring samples created was defined as 1 cm. The cut patterns of the top are shown in Figure 6.

*Figure 5: Serialized blouse basic construction*

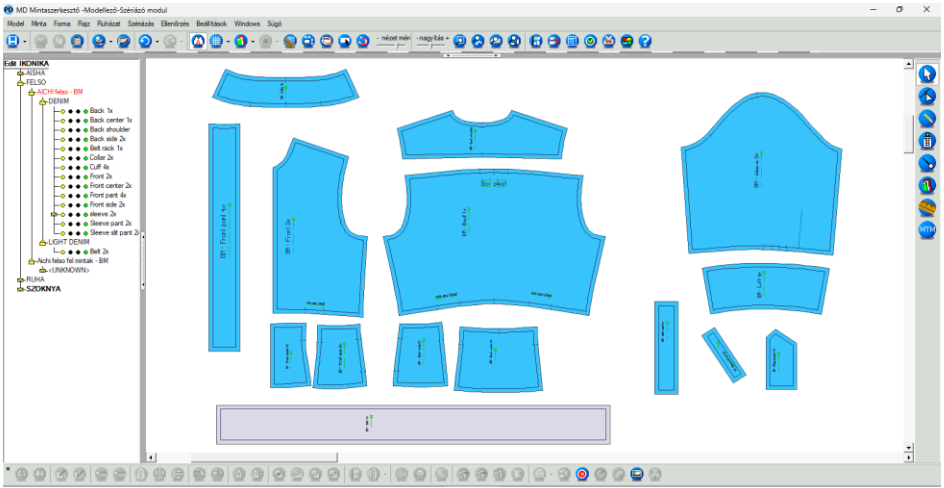

Figure 6: The AICHI tops cut patterns created in Morgan Pattern Design software

Based on the tailoring patterns, the first mock-up was completed and slightly modified based on the designer's instructions. (Fig 7)

*Figure 7: The AICHI top mockup*

**Designing the AIMOTO skirt's pattern**

Creation of the cutting patterns of the AIMOTO skirt started by editing the straight-line skirt. (Fig 8)

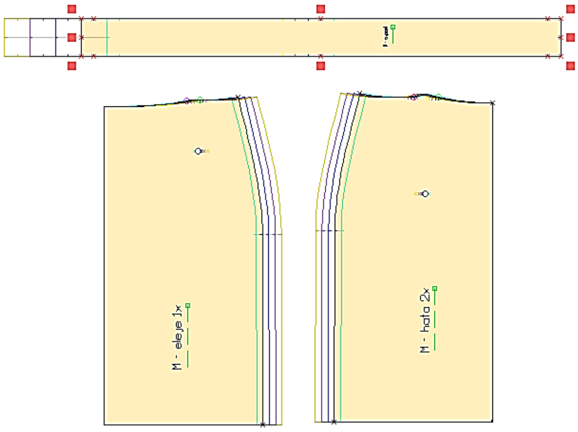


*Figure 8: Serialized straight-line skirt basic pattern*

After changing the length of the skirt, we created the flare of the skirt after closing the shaping seams. The upper part of the skirt follows the line of the body. The skirt has a pleat in the middle. The placement of horizontal cut lines runs around the front and back; they are cut from separate parts. The closure is realised with a hidden zipper on the back of the skirt and a snap on the waistband. The skirt has a patch pocket running along the side. The design worksheet of the skirt is shown in Figure 9, and the cut pattern is shown in Figure 10.


Figure 9. The design worksheet of the skirt AIMOTO

The first mock-up was completed using the tailoring samples, which were slightly modified according to the designer's instructions (Fig. 11A). At the designer's request, the skirt was adjusted to include a deeper pleat and more volume. The mock-up of the outfit, displayed on a mannequin, is shown in Figure 11B.


Figure 10: AIMOTO skirt patterns created in Morgan Pattern Design software

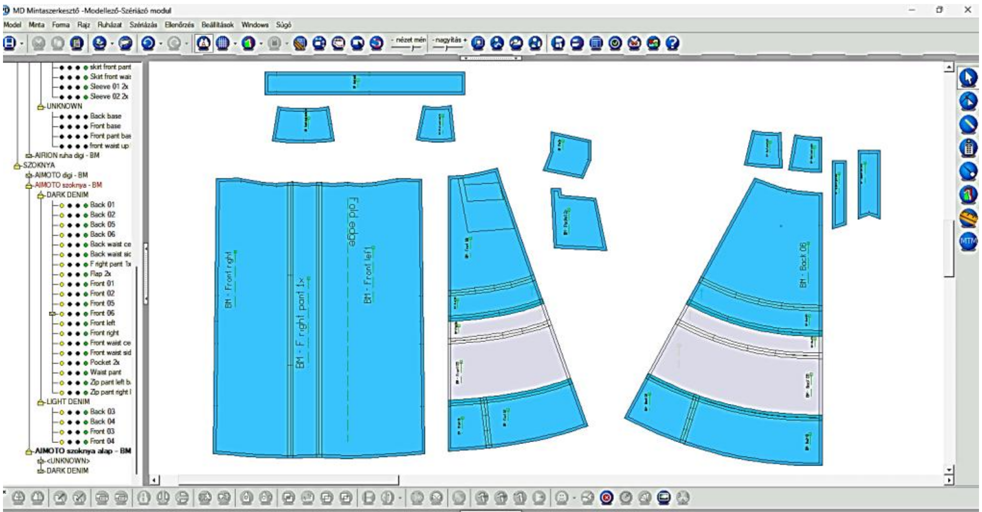


Figure 11: AIMOTO skirt mockup (A) and the final outfit on the mannequin (B)

## DISCUSSION OF THE RESULTS

During the production preparation work, the aim is to ensure the sustainability of the production. To achieve economical and optimal production, taking advantage of the possibilities of Industry 4.0, we created the tailoring patterns in digital form with Morgan Tecninca's CAD Pattern Design and Best Nest software, the advantage of which is that we can convert the files into a file format that can be opened in other software. The automatic creation of layout drawings by Morgan Best Nest shortens work processes and optimises the use of material. This method makes it easy to plan material costs.

The final stage of the design process was tailoring and sewing the products based on the digital tailoring patterns realised at Conto Bene Ltd in Serbia, Novi Pazar. The collection was presented at the VIII. International Triennial of Textile Arts at the Szombathely Gallery in August 2024. (Fig 12) [10] [11]

Figure 12: Selected pieces of the collection IKONIKA SELVEDGIKA exhibited at the VIII. International Triennial of Textile Arts at the Szombathely Gallery, August 2024

## CONCLUSION

AI is revolutionising the design and sample-making process in the fashion industry. It enables designers to explore a broader range of possibilities by generating multiple design variations from their initial concepts, enhancing creativity without replacing the human touch. AI-driven systems streamline sample creation, reducing the time and resources needed to develop prototypes. Combined with Industry 4.0 pattern-making technologies, AI optimises the entire process, from design to sample production, resulting in faster, more efficient workflows and minimising waste in the early stages of collection development. It is also an effective tool for the creation of unique art collections.

This article discussed incorporating Artificial Intelligence into the creative process, which introduces new opportunities and challenges.

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# STRATEGIES FOR INDUSTRY 5.0 ADOPTION IN TRADITIONAL INDUSTRIES LIKE TEXTILES

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**ABSTRACT**
This paper explores the transformative potential of integrating Industry 5.0 technologies within the textile industry, emphasizing the roles of artificial intelligence, the Internet of Things, and robotics. These technologies improve production efficiency, quality, and customization while promoting sustainable practices through energy-efficient processes and waste reduction. Workforce transformation is important, requiring comprehensive training programs and continuous skill development to align with technological advancements. The paper highlights the need for a skilled workforce capable of operating and maintaining these advanced systems. Comprehensive training programs and continuous skill development are essential to equip workers with the necessary competencies. Additionally, the research underscores the importance of government support through financial incentives, research and development (R&D) funding, and environmental regulations to create an enabling environment for the successful adoption of Industry 5.0 technologies. The synergy between technological advancements and human capital is important for achieving a competitive, sustainable, and innovative textile sector that can meet the evolving demands and challenges of the future.

**Key words:** Industry 5.0, transformation, technologies, R&D.

## INTRODUCTION

The integration of advanced technologies in the textile industry represents a significant shift towards modernization and efficiency. The adoption of artificial intelligence (AI), the Internet of Things (IoT), and robotics is transforming traditional manufacturing processes, enhancing productivity and product quality. AI-driven systems enable predictive maintenance, reducing downtime and operational costs, while IoT devices facilitate real-time monitoring of machinery, leading to optimized production workflows. Robotics in textile manufacturing introduces automation in tasks such as cutting, sewing, and quality inspection, ensuring precision and consistency. These technological advancements are important in addressing the challenges of modern textile production, including the demand for customized and high-quality products (Sikka et al., 2024).

Workforce transformation is essential for the successful implementation of Industry 5.0 in the textile sector. As advanced technologies become more prevalent, there is a growing need for a skilled workforce capable of operating and maintaining these systems. This necessitates comprehensive training programs and educational initiatives focused on upskilling workers. Developing a culture of continuous learning within organizations is important to ensure that employees remain proficient in the latest technological advancements. Additionally, supporting collaboration between industry and educational institutions can help bridge the skills gap, preparing the workforce for the evolving demands of the textile industry (Gangoda et al., 2023). Smart manufacturing practices are increasingly important in promoting sustainability within the textile industry. Furthermore, integrating smart manufacturing with sustainable practices not only improves operational efficiency but also aligns with the growing consumer demand for eco-friendly products. As a result, the textile industry can achieve a balance between technological advancement and environmental responsibility (Ahmad et al., 2020). Additionally, AI improves quality control by analyzing product defects in real-time, ensuring consistent quality and minimizing waste. Production processes can be optimized through AI, which enables better scheduling and resource allocation, leading to more efficient operations and cost savings (Sikka et al., 2024).

The Internet of Things (IoT) plays a important role in modernizing textile manufacturing. IoT devices facilitate real-time monitoring of machinery and production processes, providing valuable data for improving operational efficiency (Ramaiah, 2021). The integration of collaborative robots, or cobots, allows for human-robot interaction, where robots handle routine tasks while human workers focus on more complex and creative aspects of production. This collaboration increases overall productivity and enables manufacturers to adapt quickly to changing production demands (Verleysen et al., 2020).

Big data and analytics further empower the textile industry to make data-driven decisions. The vast amount of data generated from production processes, customer feedback, and market trends can be analyzed to gain insights and drive improvements. For example, data analytics can help manufacturers identify patterns in customer preferences, enabling them to develop products that meet specific market demands. Supply chain optimization is another significant benefit, as data analytics provide a comprehensive view of the supply chain, helping to identify bottlenecks and inefficiencies. This holistic approach ensures that resources are used effectively, reducing waste and improving overall supply chain performance (Hack-Polay et al., 2020). Human-robot collaboration is improved through technologies like augmented reality (AR), which provides real-time support to workers on the factory floor. AR can guide workers through complex tasks, offering visual instructions and reducing the need for extensive training. This technology improves worker productivity and reduces the time required to achieve proficiency in using new machinery or processes. Safety is also improved as AR can highlight potential hazards and ensure that safety protocols are followed (Liu et al., 2024).

Existing literature on the adoption of Industry 5.0 in traditional industries like textiles primarily focuses on individual technologies and their potential benefits. However, there is a lack of comprehensive studies that examine the holistic integration of AI, IoT, robotics, and big data analytics within the textile industry. This paper aims to fill this gap by providing a theoretical model that integrates these technologies and addresses the challenges and opportunities associated with their implementation.

## INTEGRATION OF ADVANCED AND WORKFORCE TRANSFORMATION

The integration of advanced technologies in the textile industry is reshaping traditional manufacturing processes through the adoption of artificial intelligence (AI), the Internet of Things (IoT), and robotics. AI improves decision-making capabilities by analyzing vast amounts of data to predict maintenance needs, optimize production schedules, and improve quality control. Predictive maintenance systems utilize AI to foresee equipment failures, reducing downtime and extending the lifespan of machinery. IoT devices enable real-time monitoring and data collection, facilitating the seamless coordination of production processes and ensuring efficient resource utilization. Robotics automate repetitive tasks such as cutting, sewing, and inspection, increasing precision and consistency while freeing human workers to focus on more complex and creative tasks. These technologies collectively contribute to higher productivity, lower operational costs, and the ability to produce customized, high-quality textile products that meet evolving consumer demands (Dal Forno et al., 2023). The transformation of the workforce is a important aspect of successfully integrating advanced technologies in the textile industry. As these technologies become integral to production processes, there is a growing demand for a workforce equipped with the necessary skills to operate and maintain them. This necessitates the development of comprehensive training programs aimed at upskilling current employees and preparing new entrants to the industry. Educational initiatives focused on the principles of AI, IoT, and robotics are essential for building a skilled labor force capable of adapting to technological advancements. Partnerships between industry and educational institutions can play a important role in this endeavor, offering specialized courses and hands-on training that align with industry needs (Judijanto et al., 2024). Supporting a culture of continuous learning within organizations is important to keep the workforce abreast of the latest technological developments. Encouraging employees to engage in lifelong learning and providing access to ongoing training opportunities can help ensure that they remain proficient in new tools and systems. This approach not only improves individual capabilities but also strengthens the overall adaptability and resilience of the organization in a rapidly changing technological landscape (Gangoda et al., 2023).

Workforce transformation also involves addressing the potential displacement of jobs due to automation. While robotics and AI can take over routine tasks, there is an opportunity to redeploy human workers to areas where their skills can add greater value, such as in design, quality assurance, and customer service. This requires a strategic approach to workforce planning, where employees are supported in transitioning to new roles that leverage their strengths and experience. Additionally, soft skills such as problem-solving, creativity, and communication will become increasingly important as workers collaborate with advanced technologies to drive innovation and efficiency in textile manufacturing (Allais et al., 2021; Gangoda et al., 2023).

## SUSTAINABLE AND SMART MANUFACTURING

Sustainable and smart manufacturing practices are becoming increasingly important in the textile industry as it seeks to balance economic growth with environmental responsibility. The adoption of energy-efficient technologies and waste reduction techniques plays a significant role in achieving this balance. Energy-efficient machinery and processes help reduce the overall carbon footprint of textile production, leading to lower operational costs and compliance with stringent environmental regulations. Implementing closed-loop systems, where waste materials are recycled back into the production process, further improves sustainability. Smart materials, designed for durability and minimal environmental impact, contribute to a more sustainable product lifecycle. Additionally, leveraging data analytics enables manufacturers to optimize resource use, streamline operations, and minimize waste, all of which are important for sustainable manufacturing (Gangoda et al., 2023).

Smart manufacturing integrates advanced technologies such as AI, IoT, and robotics to create more efficient and responsive production systems. AI-driven analytics provide insights into production processes, helping identify areas for improvement and predict maintenance needs, thereby reducing downtime and enhancing productivity. IoT devices facilitate real-time monitoring of machinery and inventory, ensuring optimal performance and reducing material wastage. Robotics automate repetitive and labor-intensive tasks, increasing precision and consistency while reducing human error. These innovations not only improve the efficiency and quality of textile production but also support the industry's move towards more sustainable practices. For example, precise automation and real-time data analysis can significantly reduce water and energy consumption, addressing some of the most pressing environmental challenges faced by the textile sector (Ahmad et al., 2020). Economic policy implications are a important aspect of the textile industry's transition towards sustainable and smart manufacturing. Governments play a important role in creating an enabling environment through policies that incentivize the adoption of advanced technologies and sustainable practices. Financial incentives such as tax credits, subsidies, and grants can encourage investment in energy-efficient equipment and research into sustainable materials. Regulatory frameworks that set standards for environmental performance push companies to innovate and adopt best practices (Ramaiah, 2021). Trade policies also have significant implications for the textile industry. International agreements and regulations can influence market access and competitiveness. Policies promoting sustainable and ethical production practices can improve the industry's global reputation, attracting environmentally conscious consumers and investors. Conversely, protectionist measures or tariffs on imported materials and technologies can hinder the industry's ability to innovate and compete globally. Hence, a balanced approach to trade policy is essential to support the industry's sustainable growth (OECD, 2021). Investment in infrastructure is another important policy consideration. Public-private partnerships can facilitate the development of such infrastructure, ensuring that even small and medium-sized enterprises (SMEs) can participate in the transition to smart manufacturing (Pazilov et al., 2020). Through strategic investments and supportive policies, the textile industry can achieve a sustainable and technologically advanced future (Pazilov et al., 2020).

Based on the analyzed literature, a theoretical model is developed to illustrate how the integration of Industry 5.0 technologies can transform the textile industry. This model, presented in Figure 1, outlines the roles of AI, IoT, robotics, and big data analytics in optimizing production processes, improving product quality, and promoting sustainability.

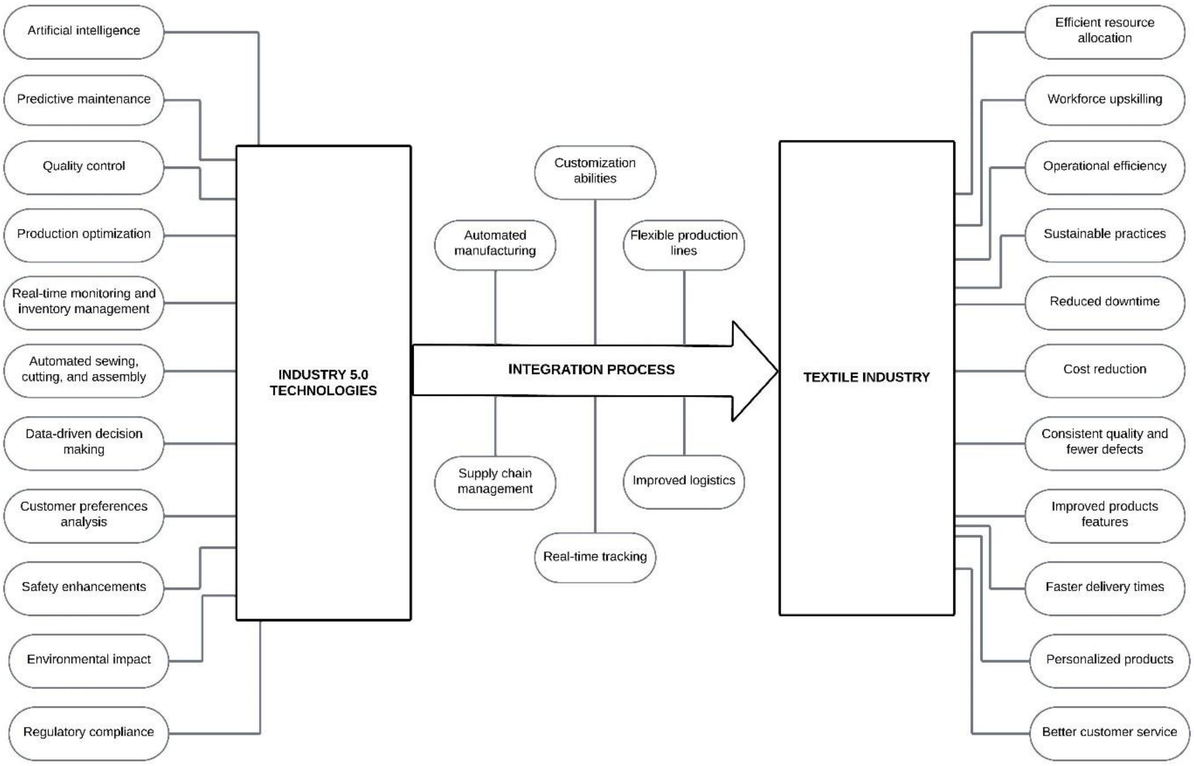


*Figure 1: Model for improving the textile industry through Industry 5.0 technologies*

The integration of Industry 5.0 technologies significantly transforms the textile industry, improving efficiency, quality, and sustainability. Artificial intelligence (AI) improves predictive maintenance by analyzing machine data, preventing failures, and reducing downtime, while also optimizing production schedules and ensuring consistent product quality. The Internet of Things (IoT) enables real-time monitoring and tracking, improving inventory management, machine performance, and workflow coordination. Robotics automates tasks like sewing and cutting, increasing precision and reducing human error, while collaborative robots (cobots) combine human creativity with robotic efficiency. Augmented reality (AR) provides real-time guidance, reducing training time and supporting workers in complex tasks. Big data and analytics empower decision-making by providing insights into production, customer preferences, and market trends, optimizing supply chains and enabling product customization. Automated manufacturing increases throughput, reduces labor, and allows flexible production lines that adapt quickly to new designs. Customization capabilities cater to individual preferences, enhancing market appeal. Supply chain management benefits from improved logistics, real-time tracking, and efficient resource use, reducing waste and improving delivery times. Workforce dynamics shift with the need for skill development and upskilling, creating new roles in AI management, data analysis, and robotic maintenance. Sustainability is improved through energy-efficient technologies, waste reduction techniques, and eco-friendly materials, aligning with environmental regulations and consumer demands. Quality and compliance improve through advanced monitoring, ensuring high product standards and regulatory adherence.

## SUGGESTIONS AND GUIDELINES

Based on the developed theoretical model and the reviewed literature, the following guidelines and suggestions are proposed for effectively integrating Industry 5.0 technologies into the textile industry:

- Provide tax credits and subsidies for enterprises adopting AI, IoT, and robotics in textile manufacturing. These financial incentives can reduce the initial investment burden and encourage widespread technological adoption.
- Fund R&D programs focused on sustainable materials and smart manufacturing techniques. Collaborative efforts between research institutions and industry can accelerate innovation and practical application.
- Implement strict environmental regulations that mandate sustainable practices in textile production. These regulations should be accompanied by support systems to help companies transition to greener processes.
- Invest in education and vocational training programs to upskill the workforce in new technologies. Partnerships with educational institutions can create curriculums that meet industry needs.
- Encourage collaboration between government bodies and private enterprises to develop infrastructure supporting Industry 5.0 technologies. Such partnerships can drive large-scale industrial modernization efforts.
- Implement AI, IoT, and robotics systematically across production lines to improve efficiency and product quality. This integration should include both hardware upgrades and software solutions for maximum impact.
- Transition to energy-efficient machinery and adopt waste reduction techniques such as closed-loop systems. Sustainable practices not only meet regulatory requirements but also appeal to environmentally conscious consumers.
- Establish ongoing training programs to keep employees updated with the latest technological advancements. Encouraging a culture of continuous learning ensures the workforce remains adaptable and skilled.
- Utilize big data and analytics to optimize production processes, supply chain management, and customer engagement. Data-driven strategies can significantly improve operational efficiency and market responsiveness.

## CONCLUSION

The transformation of the textile industry through the integration of Industry 5.0 technologies represents a important shift towards improved efficiency, quality, and sustainability. The adoption of advanced technologies such as artificial intelligence, the Internet of Things, and robotics significantly impacts production processes, supply chain management, and workforce dynamics. AI-driven predictive maintenance, real-time monitoring enabled by IoT, and the precision offered by robotics collectively improve operational efficiency and reduce costs. These technologies facilitate the production of customized, high-quality products, meeting the evolving demands of consumers and increasing the competitiveness of textile manufacturers. Future research should focus on empirical studies that validate the proposed theoretical model by analyzing case studies of textile companies that have successfully integrated Industry 5.0 technologies. Comparative studies across different regions or textile sub-sectors could provide insights into the unique challenges and opportunities associated with these technologies. Additionally, research could explore the role of government policies and economic incentives in supporting the adoption of Industry 5.0 technologies in traditional industries.

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# SUSTAINABILITY IN A SLOW FASHION COLLECTION

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**ABSTRACT**

This research addresses the most pressing issues facing the textile industry and offers a solution that prioritizes sustainability. Our goal is to create a collection for the European market that fully utilizes local resources and serves as a worthy representative of slow and sustainable fashion. The materials used in the collection are linen fabrics made from plant fibers.

In the patterning of the collection, unique dyeing and printing techniques were prioritized, focusing on minimizing environmental impact. The article presents research into ancient dyeing techniques from various cultures around the world. After experimenting with these selected techniques, an ancient Japanese method, Tataki-zome, emerged as the most beneficial in a number of ways. In addition to its natural, aesthetic appearance, it has the advantage, that only compostable parts of plant elements with minimal moisture content are left as waste after the patterning process. The collection's pieces are designed according to the principles of zero-waste pattern design, meaning that the models are made without shaping, using simple geometric elements in a variety of combinations. Reflecting the zero-waste ppattern design and the use of raw plant elements, the collection is called "ZERAW."

**Key words**: 1. sustainability, 2. Tataki-zomé, 3. zero-waste, 4. hemp

## INTRODUCTION

The climate change currently underway can be traced back to the Industrial Revolution. The globalization brought about by industrialization has led to a series of environmentally harmful human activities, which have caused the global warming we are experiencing today. Geological research shows that numerous climate changes have occurred on the Earth's surface throughout its history. However, it is likely that this is the first one caused by an extremely complex series of incorrect human activities.

The main cause of the problems leading to global warming is industry. The fashion industry is currently considered the second largest polluting industry in the world, right after the oil industry. The textile industry has both direct and indirect impacts on global warming. More than 60% of textiles are used by the clothing industry. More than half of the world's textile factories are located on the Asian continent, in China, India, Bangladesh, and Indonesia. Most of the textile factories operating in both these countries and European countries run on coal, contributing to 10% of the annual global carbon dioxide emissions.

### The Role of the Fashion Industry in Environmental Pollution

**• Water Pollution**
An estimated 97% of the Earth's water supply is made up of salty oceans and seas. Of the freshwater available to us, according to some records, households use 8%, industrial activities consume 22%, and 70% is allocated for irrigation. The fashion industry uses an enormous amount of clean water for textile production—an estimated 79 billion cubic meters globally each year, which accounts for 2% of our freshwater supply. Based on current consumption trends, this figure could double by 2030. [1]

**• Soil Pollution**
The artificial substances used in cotton production are another major source of water and soil pollution. Conventionally grown cotton requires large amounts of pesticides to ensure healthy crops. Poor-quality fertilizers with excessively high nitrogen content have a particularly damaging effect on soil quality, and they also release nitrous oxide into the atmosphere, which has a more harmful impact on the ozone layer than carbon dioxide emissions.

**• Fast Fashion**
The fashion industry has completely transformed over the last three decades. While fashion seasons used to be divided into two or four parts, today's clothing market with its 52 micro-seasons pushes consumers to buy more and more.

Due to the accelerated pace of fashion, global garment production doubled between 2000 and 2014 and has continued to show steady growth since. The average person now buys 60 percent more clothing annually and keeps their items for about half as long as they did 15 years ago. As consumption increases, so does the amount of discarded textiles that end up as waste. [2]

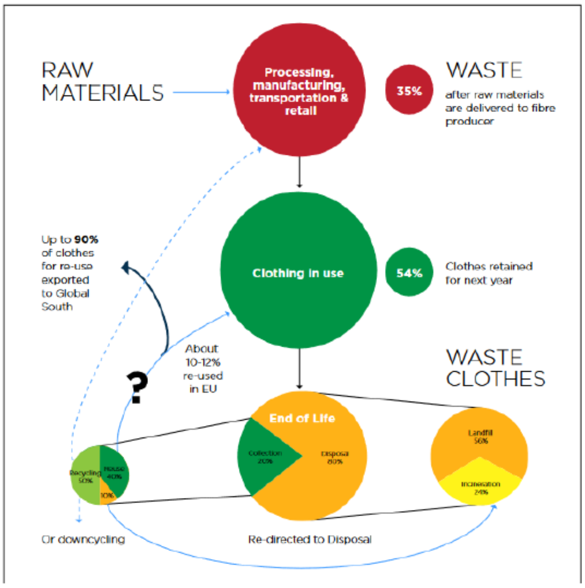


Figure 1. Clothing that ends up as waste each year - Fashion at the crossroads, Greenpeace [2]

**Reuse and Recycling**

People are trying to respond to factory overproduction through reuse and recycling. Various organizations have set up collection points to return used clothing gathered by the public back to the market. Garments that are not resold after collection are transported to recycling plants. However, the entire recycling process is very time-consuming and, as a result, not a particularly cost-effective procedure. [3]

## EFFORTS FOR AN ETHICAL AND SUSTAINABLE FASHION INDUSTRY

### Fair Trade Fashion

Fair trade fashion refers to fair trade in the clothing industry, where products must be made in accordance with ethical trade standards. The fair trade fashion movement seeks to help manufacturers and producers in developing countries establish fair conditions. These principles provide space and opportunity for the slow fashion movement to gain popularity. [4]

## A Slow Fashion Movement

Slow Fashion is a mindset that places conscious thinking about fashion as its core value. Followers of the movement aim to return to pre-industrial ways of thinking, emphasizing the art of garment-making and supporting artisans as well as green technologies.

Key characteristics of a Slow Fashion brand include:

• Producing items from high-quality, sustainably sourced materials,
• Choosing local, regional markets as the primary points of sale,
• Prioritizing local producers for sourcing materials,
• Creating 2-3 collections per year for sale.

The focus is on creating timeless, high-quality garments with enduring fashion value. This allows consumers to develop an emotional attachment to their clothing, encouraging them to treat it with care. [5]

## Domestic Precedents

The design and execution of sustainable collections began to gain strong momentum in the early 2010s, both domestically and internationally.

Botanika was founded in 2012 by Sára Hajgató. The aim of her business is to connect urban lifestyles with nature, avoiding harmful chemicals and instead using dye plants and the art of natural hand-dyeing to create clothing and accessories. [6]

Founded in 2014, Kamorka Design was one of the first in Hungary to embark on the path of organic design. The brand's philosophy is that expressing individuality through clothing can be achieved in a sustainable way. To this end, everything from design to production takes place in Hungary. They work exclusively with natural textiles, most of which are certified by the Global Organic Textile Standard (GOTS), and their collections focus on comfort and durability. [7]

Figure 2.: Kamorka design [7]

**Market Research**

From the perspective of social responsibility, we have chosen pregnant women as our target group. They are the ones who often become extremely sensitive to their environment and, through their ifestyle, take on significant responsibility for another person's well-being and future behaviour. After analysing the survey, we observed many gaps in the possibilities for an environmentally conscious lifestyle. Two-thirds of the 150 respondents are not familiar with the Slow Fashion movement. While they are mostly aware of the potential allergic effects of toxic dyes, they are not sufficiently informed about their presence or how to avoid them. 62% would buy eco-friendly maternity clothes if they knew of any brands. To promote home sewing and craftsmanship, they would gladly purchase product packages containing semi-finished, easy-to-assemble models.

## NATURAL PAINTING AND PATTERNING TECHNIQUES

Researchers trace the history of textile dyeing back to the end of the Stone Age, when textiles were dyed with substances extracted from common, locally available plants. Clothing with permanently vibrant colours was considered a luxury item. Most natural dyes were obtained from plant parts: roots, fruits, bark, leaves, and stems. In the early 1800s, English chemist William Henry Perkin accidentally discovered the first synthetic dye, aniline. After Perkin’s discovery, the possibilities provided by organic chemistry led to the unstoppable spread of synthetic dyes.

The oldest and simplest form of textile dyeing is using dye plants for colouring. We know of countless plants capable of dyeing, but only those that can produce lasting colour are considered true dye plants. These are used with natural textile materials, which must be boiled in alkaline water before dyeing so the fibres soften and become easier to dye. The acidity of the dyeing substance can regulate the durability of the dye and how well it stays in the material. [8]

• The **Ice-Flowers** technique, developed by India Flint, a nomadic botanist, allows for the extraction of purple and deep red colours from flowers using a freezing method.
• **Resist dyeing** is the most traditional type of textile patterning. A layer that resists dyeing is applied to the material by chemical or mechanical means. The two most well-known resist dyeing techniques are tie-dye and batik.
• **Eco-Print** is a textile patterning technique in which flowers, leaves, or entire plants are used to leave their shape and colour on the fabric through so-called printing. The eco-print technique is most commonly used on animal-derived fabrics, particularly wool or silk, but it can also be applied to cotton, linen, hemp, and other plant fibres. Leaves are placed between two layers of fabric and tightly rolled. To fix the prints, the fabric is placed over hot steam for about 2 hours. The durability of the prints can be increased by keeping the material warm and delaying the unrolling. At the end of the process, the fabric is briefly soaked in water with baking soda to neutralize the iron sulphate, and then the fabric can be cleaned with a simple neutral pH detergent.
• Tataki-zomé is a traditional Japanese method for creating patterns on textiles, paper, or other surfaces using raw plants. This technique is extremely simple but requires practice and attention to achieve a beautiful result. Raw leaves, flowers, or entire plants are placed on the surface to be patterned, then covered with another absorbent surface to remove excess moisture, and a heavy object like a hammer is used to mechanically transfer the pattern. Afterward, the plant material is removed from the surface. The technique can be used with virtually any plant, though its effectiveness depends on the plant’s pigment content, moisture, stiffness, and waxiness. For textiles, the durability of the patterns depends on the type of fabric, the fixing technique, andthe type of washing used. [9]

Figure 3.: Eco-print technique and the Tataki-zomé patterns on cotton fabric (source: https://www.instructables.com/ECO-PRINTING-on-Silk-and-Cotton-Fabric/)

**Painting and Patterning Experiments, Results and Experiences**

For the dyeing experiments, we selected linen fabric, linen-ramie blend fabric, raw linen canvas, and hemp fabric. We used cotton as an inverse auxiliary material for experimenting with the Tataki-Zomé method.

Calcium carbonate, commonly known as chalk or limestone, is the most suitable mordant bath for thefour samples. Calcium carbonate powder is easily obtainable, as it is also used in winemaking to regulate acidity and is an environmentally friendly choice.

The recipe for the calcium carbonate bath is based on a description by Botanical Colours [10]:
• 100 grams of dry vegetable fibre
• 5 grams of calcium carbonate
• 500 ml of water

One-third of the fabrics prepared for dyeing were placed in a pre-prepared beet dye. The remaining forty samples were prepared for patterning without dyeing. We applied the Eco-Print technique to five samples of each fabric type, and the Tataki-zomé technique to the remaining samples.

The Eco-Print patterns were created as previously described. The plants were collected from our own garden and soaked in a mixture of vinegar and water for 6 hours before use. The iron solution was made by soaking rusty nails in water and adding vinegar. The prepared textiles were then placed over steam for two hours.

Despite its extreme simplicity, the Tataki-zomé technique presented many challenges. For sustainability, we wanted to use plants that could easily be sourced from nearby wild-growing areas. We primarily examined the properties of plants considered weeds or invasive species, but not harmful to humans, in an effort to minimize the ecological footprint of the experiments. Using pre-prepared fabric samples, we tested various plants. During the experiment, achieving a smooth surface and even patterns required understanding the properties of the plants. The shape and weight of the hammer also had to be adjusted to the moisture content of the plants. The results of the experiment are shown in Figures 4 and 5.

Figure 4.: Eco-print patterning method on four types of fabric samples

Figure 5.: Tataki-zomé patterns with field plants

In the **Tataki-Zomé** patterning, moving from left to right, the plants used are: hoary plantain, fumitory, common yarrow leaves, tufted vetch, elecampane, and wild parsnip.

After experimenting with dyeing and patterning, considering several factors (tool, material, and labor requirements, as well as durability, reactivity, and overall effect), we evaluated the different materials and techniques. This led us to choose linen as the fabric and the Tataki-Zomé technique.

**MODELLING METHOD**

Before starting the modelling experiments, we conducted a form-finding study to create simple and clean shapes, and to minimize environmental impact using zero-waste cutting techniques.

Zero-waste design refers to a process in which 100% of the available fabric is utilized, reducing waste to zero.

The collection's style is minimalist, aiming for a natural appearance, based on the complete elimination of unnecessary elements and design features. An important part of the concept is the comprehensive consideration of environmental and health protection aspects, while ensuring high quality to maximize the durability and lifespan of the products.

During the cutting process, the use of geometric shapes allows for simple lines without shaping seams, which are further emphasized by the natural fastening solutions of the garments. In the design of the clothes, we also prioritized ease of wear and comfort.

Figure 6.: Mock-ups and lay-up drawing on 140 x 150 cm fabric

As a preliminary step to collection design, we determined the most suitable production methods for the models, in line with the environmentally conscious principles of slow fashion. The patterns were designed individually, based on the customers' preferences for colour and shape. In personal design, the focus is on the individual's personality and style, making the product feel more personal. Consumers tend to value and care for items they perceive as personal, which, along with high quality, helps extend the lifespan of our products. Reflecting the zero-waste pattern design and the use of raw plant elements, the collection is called 'ZERAW'.

The model designs are shown in Figure 7, and photos of the completed garments are in Figure 8.

Figure 7.: Fashion sketches of 10 models from front view

Figure 8.: Models of the finished collection

**CONCLUSION**

This research and experimentation, along with the creation of the sustainable collection, highlighted that there is an alternative to the mass-produced products of today's fast-paced, wasteful fashion industry.
Examining the market potential of the ZERAW collection, a survey-based market research conducted with 150 participants revealed that they were all open to purchasing environmentally conscious products; however, there is a significant need for raising awareness about the issue.

In the search for the ideal material, we conducted natural dyeing and patterning experiments on the tested fabrics. Based on the analysis, we chose linen as the main material for the collection. Its reintroduction into the textile market could significantly reduce the ecological footprint of material production.

For the concept of natural design, the Tataki-Zomé technique proved to be the most suitable patterning method, while in zero-waste design, the minimalist style with simple lines was emphasized.

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# SUSTAINABILITY IN FASHION. REDISCOVERING TRADITIONAL TEXTILE TECHNIQUES FOR A SUSTAINABLE FUTURE

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**ABSTRACT**

Sustainability in fashion is not just a trend but an urgent necessity in the context of current ecological and social crises. As global awareness of these issues grows, the fashion industry is increasingly pressured to rethink its production and consumption models, considering the long-term impact on the planet and society. Textile techniques can become a powerful tool in designing and promoting sustainable fashion and a more conscious and responsible lifestyle.

**Keywords**: sustainability, recycling, textile techniques, felting, embroidery, Sashiko, Chenille

## INTRODUCTION

The purpose of this article is to emphasize the importance of adopting traditional and artisanal textile design techniques in fashion sustainability, which can be achieved through a series of creative and effective strategies such as dry felting, textile printing, embroidery (including Sashiko), and the Chenille technique. I have experimented with these techniques alongside students from the Faculty of Arts and Design, specializing in Fashion-Design and Decorative Arts-Textile Design.

Sustainability in fashion is crucial for creating a balance between current needs and the ability to protect the planet and society for future generations. The fashion industry is one of the most polluting industries globally. Mass production and fast consumption of clothing generate large amounts of textile waste, carbon emissions, and chemical pollution, contributing to environmental degradation.

### Fast Fashion

Fast Fashion encourages frequent purchases and the discarding of clothes after a short period of use, leading to increased textile waste that ends up in landfills or is incinerated. Textile production, especially cotton, requires large amounts of water, putting pressure on freshwater resources in regions already affected by drought and climate change. The extraction and processing of raw materials for textiles, such as petroleum for polyester, contribute to the depletion of natural resources and environmental pollution.

In many textile-producing countries, workers face low wages, unsafe working conditions, and excessive working hours. Sustainability in fashion also includes aspects of social justice, promoting ethical production and respecting workers' rights. Consumers are becoming increasingly aware of the impact of their clothing choices and demand products that are manufactured responsibly, both ecologically and socially. Access to information and awareness campaigns promoted through social media and other digital channels have contributed to the growing interest in sustainable fashion.

There are step-by-step tutorials showing how these techniques can be used to create durable clothing or to refurbish old garments. Visual posts on platforms like Instagram, YouTube, Pinterest, or TikTok share images and videos demonstrating the use of traditional textile techniques in fashion design.

The fashion industry is responsible for a significant percentage of global CO2 emissions. Adopting sustainable practices helps reduce this footprint and combat climate change. There is an increasing demand for innovative solutions such as eco-friendly materials and low-impact production processes that contribute to a greener future.

An example would be fabrics made from ocean plastic waste, which represent an important innovation in sustainable fashion, addressing two major problems: ocean plastic pollution and the negative impact of conventional textile production on the environment. The process involves collecting, cleaning, and processing plastic, which is then transformed into textile fibers such as recycled polyester. The production of recycled fibers from plastic generates fewer carbon emissions compared to the production of new fibers from petroleum-based raw materials. This innovation not only helps clean the oceans but also demonstrates how the fashion industry can adopt more eco-friendly and sustainable solutions.

Promoting and developing applied textile design techniques in specialized courses and creative workshops can form new generations of designers who will continue to innovate and redefine fashion by using these techniques.

**Techniques Such As Wet Felting, Dry Felting, And Nuno-Felting**

Techniques such as wet felting, dry felting, and nuno-felting are used to create unique and artistic textile pieces, each with its own particularities. However, there are some similarities between them, especially in the context of fashion design: they use the same basic material: wool or natural fibers such as silk or cotton. Wool fibers are manipulated to interlock and fix together, forming a solid textile material. In the case of wet felting and nuno-felting, water and soap are used to facilitate this process, while dry felting uses a special needle to compress the fibers. These techniques are often used to create unique clothing pieces such as garments, scarves, hats, or accessories due to the manual nature of the process.

There are several essential differences between wet felting, dry felting, and nuno-felting techniques that influence how they are used in fashion design. Wet felting uses warm water and soap to help wool fibers interlock and fix together. The process involves manual rubbing and pressing of the fibers until they compact and form a solid material, which requires a lot of manual labor.

Dry felting (with a needle) involves manipulating wool fibers with the help of a special needle with small barbs. Through repeated needle pricks, the fibers compress and tangle, forming a compact material. No water or soap is used, and this technique offers greater control over fine details. Although it may be quicker for small pieces or details, it is a meticulous process when working on larger or more complex pieces. It is ideal for creating precise details and sculptural shapes.

Nuno-felting combines wet felting with the use of a base material such as silk on which wool fibers are placed and felted. Water and soap are used to make the wool fibers adhere to the base fabric, creating a lightweight and airy composite textile material. It is a more complex technique because it involves integrating multiple materials. It requires knowledge of both wet felting and handling thin fabrics but allows the creation of very special materials with unique properties.

a) b) c)

Figure 1. a) *Making a clothing product by wet felting, b) Shawl made by Nuno felting c) Dry felting on the denim jacket*

**Embroidery**

Embroidery is done through decorative stitches applied either by hand or with a sewing machine. It is a traditional decorative technique that adds aesthetic and cultural value to each garment.

It can revive old or damaged clothes, extending their life and preventing waste. Traditional motifs are creatively reinterpreted, contributing to the exploration and innovation of modern aesthetics. It is a meticulous and time-consuming process, resulting in high-quality products with fine details and increased durability. Natural or organic threads and materials (such as mercerized cotton, recycled cotton, organic silk, linen threads, etc.) are used, which are more environmentally friendly. By promoting these materials, the fashion industry can reduce its negative impact on the environment, such as carbon emissions and water pollution.

*a)*

*A) b)*

*Figure 2: a) Handmade embroidery on denim jacket* *b) Handmade embroidery on silk veil*

*a) b) c)*

*Figure 3: a) Hand made embroidery on the denim jacket, b) Embroidery on sports blouse, c)E.E. Riemschneider, embroidery*

**Japanese Sashiko Embroidery**

Japanese Sashiko embroidery is a traditional technique originally used for repairing and reinforcing fabrics, combating the habit of discarding clothes after wear, and aligning perfectly with the sustainability trends in contemporary fashion. At the same time, it adds a unique decorative element, transforming an old or damaged garment into a piece of textile art.

It consists of small, repeated, dense stitches that not only repaired but also provided insulation against the cold. These stitches are made on the surface of the fabric, and the technique involves passing the thread through multiple points at once, resulting in a series of straight and regular lines, usually in a simple geometric pattern. Unlike traditional embroidery, Sashiko is more about regularity and repetition than the complexity of the stitches.

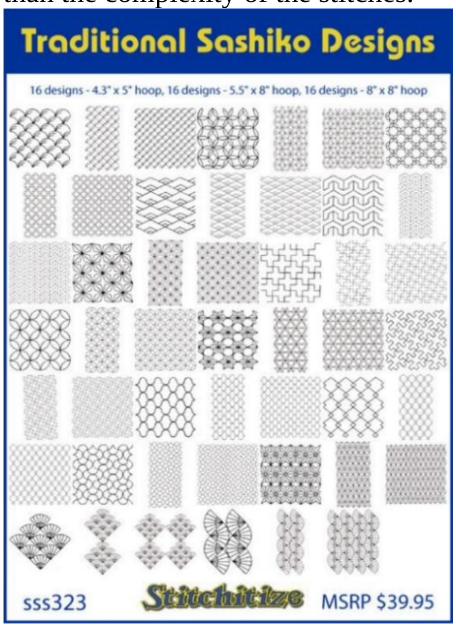


*Figure 4:Traditional Sashiko Design Patterns*

*Figure 5: Sashiko Design Stitched Patterns*

White cotton threads are often used on natural fabrics, typically blue or indigo cloth, giving Sashiko its distinctive appearance. In sustainable fashion, organic or recycled materials can be used, thereby reducing environmental impact.

By repairing and personalizing old clothes using Sashiko, designers and consumers help reduce material waste and extend the lifespan of clothing items. This approach promotes a conscious and sustainable lifestyle, emphasizing the Japanese philosophy of resource conservation.

*Figure 6: Denim jacket with Sashiko embroidery on the back*

*Figure 7: Sashiko technique sewn on patches of fabric*

*Figure 8: Sashiko embroidery on jacket and denim jeans with colored thread*

**Chenille Technique**

The Chenille technique involves layers of cut fabrics to create a textured and velvety effect, which can transform fabric scraps or old clothes into new and attractive pieces, contributing to the reduction of textile waste.

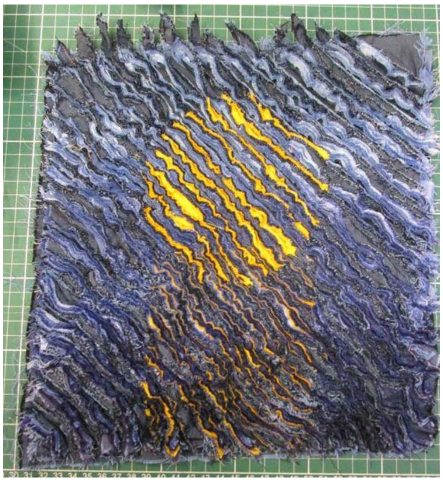

*Figure 9: Chenille technique*

*Figure 10: Detail*

Two layers of basic material are used, a lower one on which scraps of fabrics, fibers, natural threads are placed that overlap in several rows creating a decorative composition, and a second upper material on which drawings are made. The more colorful the materials, the more interesting the result. Fix everything with a temporary adhesive spray. Draw parallel lines 2-3 cm wide on the face of the material, which can be straight or curved. Pin all the materials then start sewing along the drawn lines. It is similar to the quilting technique.

Next is the cutting of the material between those sewn lines with the help of a special-cutter device that makes this much easier and faster, or with scissors in its absence. Great care must be taken when cutting so as not to cut the lower material, i.e. the base. Next comes the washing process in the washing machine. It is also possible to intervene, when the material is dry, with a wire brush on the edges of the cut rows, helping to unravel the threads to achieve a fluffy texture.


*Figure 11: Chenille cutte*

Chenille allows for a high degree of customization and innovation, giving sustainable designers the opportunity to create unique and memorable pieces that appeal to consumers who value both beauty and environmental responsibility. It is a technique that creates a versatile and elegant material, widely used in various interior design and fashion applications, due to its pleasant texture and sophisticated appearance.

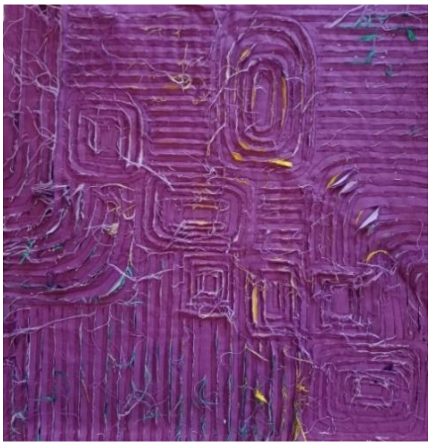

*Figure 12: Lavinia Toader, 1st year student 2023-2024 FAD*

*Figure 13: Ana Percea, 1st year student 2023-2024 FAD, sketch-materials-finished work*

*Figure 14: Chenille technique on the bag*

*Figure 15: Chenille technique on jacket*

[2]

*Figure 16: Denim vest customized by Chenille technique*

Chenille is less commonly used in garments such as sweaters, jackets or even scarves. The material is soft and warm, which makes it ideal for cold season clothing. Plus, its bright and full look adds a touch of style to any outfit.
By combining traditional techniques with modern shapes and innovative materials, designers create pieces that are both functional and aesthetically pleasing, with an emphasis on detail and craftsmanship. Reusing and refurbishing old clothes by adding new details or transforming them through different methods can extend the life of clothing products and reduce material waste. This is an innovative solution to combat environmental issues related to the fashion industry.
Innovative techniques can redefine the concept of luxury in fashion. Rather than relying on expensive materials, luxury can be defined by attention to detail, craftsmanship and the uniqueness of each piece. This kind of luxury gives value to clothes not just through the materials used, but through the time, effort and creativity involved in the design and execution process.

Innovation and creativity allow designers to experiment with new materials and textures, transforming the traditional canvas into a limitless creative medium. For example, smart materials, such as textiles that change color or texture depending on temperature, enable the creation of dynamic garments that interact with the environment.

The integration of advanced technologies, such as 3D printing on textiles or digital embroidery, allows the creation of complex and detailed designs that would not be possible with traditional methods. These innovations open new horizons in clothing design, offering the possibility to customize and create unique pieces, adapted to the needs and preferences of each individual. Sustainability in fashion promotes the use of renewable, recycled or biodegradable materials that have a lower impact on the environment.

## CONCLUSION

In an era where the fashion industry is under increasing pressure to adopt sustainable practices, traditional techniques such as felting, embroidery, Sashiko, Chenille and others are proving to be not only artistic methods, but also valuable solutions for a future more sustainable. These techniques not only extend the life of clothes and reduce waste, but also revalue the craft, supporting local communities

[2] https://ro.pinterest.com/pin/114208540542524591/

and promoting responsible consumption. Incorporating these methods into contemporary fashion design not only enriches each piece aesthetically, but also provides a tangible way to reconnect with traditions and the environment. Thus, fashion can become a catalyst for change, combining beauty with responsibility, and proving that personal style can go hand in hand with ethics and sustainability.

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# FASHION DATABASE: FASHION REQUIREMENTS AND BASIC DESIGN ELEMENTS

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**ABSTRACT**

The fashion industry is rapidly embracing digitalisation. It is therefore necessary to quickly learn the techniques of digital fashion design using appropriate design resources integrated in a relatively complete digital environment (databases, design knowledge bases, interfaces). As part of the Erasmus+ project Digital Fashion (2021-1-RO01-KA220-HED-000031150), a new online platform is being developed to support the teaching and learning of digital fashion with a knowledge library for virtual fashion design through personalised virtual 3D garment fitting. This platform contains three main knowledge databases: one for textile materials, one for garment models and one for 3D models of the human body, resulting in simulations of 3D prototypes of garments for the chosen garment/body size and textile. Teaching materials such as the fashion database, the fabric database, the garment database and e-shopping for garments have been developed for teaching and learning digital fashion design and are also part of the Digital Fashion platform. This paper briefly introduces the Digital Fashion platform and the teaching material for the fashion database, which emphasise the importance of design elements in digital fashion design.

**Key words**: Erasmus+, Digital Fashion project, e-learning, online platform, fashion database

## INTRODUCTION

The fashion industry is undergoing a rapid transformation driven by digitalisation, reshaping design, production and education. In response to the growing demand for digital fashion skills, the Erasmus+ project Digital Fashion (2021-1-RO01-KA220-HED-000031150) is developing an innovative online platform that supports the teaching and learning of digital fashion. The platform provides a comprehensive knowledge library for virtual fashion design that presents simulations of virtual 3D garments depending on the chosen size of the garment and textile material. It integrates extensive databases of textile materials, garment models and 3D human body models to provide students and professionals with invaluable resources for the creation of virtual 3D garment prototypes.

The Erasmus+ project DigitalFashion, officially called Collaborative Online International Learning in Digital Fashion, is a three-year initiative launched in February 2022. It is coordinated by the National Research and Development Institute for Textiles and Leather (INCDTP) in Romania. It is co-funded by the European Commission's ERASMUS+ program under the Strategic Partnerships for Higher Education. The project partners include the National Higher School of Arts and Textile Industries in France (ENSAIT), the Hogent University of Applied Sciences and Arts Gent in Belgium, the University of Maribor in Slovenia, the Textile and Clothing Technological Center (CITEVE) in Portugal, and the Gheorghe Asachi Technical University Iasi in Romania. The Erasmus+ project DigitalFashion is the fifth in a series of successful projects dedicated to e-learning in the wider textile sector. The projects were carried out by a consortium made up of universities and institutes from various European countries. The first project of this type was entitled E-learning course for advanced textile sectors – Advan2Tex and was carried out in the period 2014-2016. As part of the Advan2Tex project, a Moodle online teaching/learning platform was developed (https://www.advan2tex.eu/portal/), and serves as an educational platform for all five projects. The Knowledge Matrix for Innovation and Competitiveness in Textile Enterprises – TexMatrix project followed in the period 2016-2018. The Advan2Tex project aimed to provide e-learning content for textile professionals, young entrepreneurs and students in higher education. Seven e-learning modules were developed to encourage the target groups involved to apply the knowledge in their own textile businesses. The TexMatrix project was based on an organisational management tool called Knowledge Matrix for Innovation, which was used to quantify/improve the intangible assets of the innovation capability of the participating textile companies. The third project, Skills4Smartex - Smart textiles for STEM training, was implemented in the period 2018 -2020. It was a strategic partnership - KA2 - VET, in the field of innovation transfer from research institutions to textile companies and VET institutions. The fourth project, OptimTex - Software tools for textile professionals, is entirely focused on the new trends in the digitalisation of the entire textile and clothing sector. This project aimed to improve the knowledge and skills of university students in the field of software applications and to increase their employability in textile companies by providing appropriate training tools for their profession (Penko T. et al., 2022).

The main results of the project are: PR1. New methodology for a common framework for collaborative international online learning in the field of digital fashion; PR2. Knowledge library (the three databases) for virtual fashion design and technology; PR3. Training platform for fashion design through simulations of 3D virtual garment prototypes; PR4. Curricula for collaborative international online learning in the field of digital fashion. The first project result analysed the digital skills required for virtual prototyping technologies in fashion and clothing companies in five European countries. A survey of 35 fashion and clothing companies was conducted to assess their digital skills and use of virtual fashion technologies and to develop a methodology for online collaborative learning in the digital fashion sector. The analysis of the survey revealed that virtual fashion technologies are desirable in the apparel development process. The results also show a clear need for training in the field of digital fashion and a need for the profession of 3D designer, Figure 1. To address this, the project partners have started to develop a training platform in the next phases of the project, focussing on virtual 3D garment prototypes and based on the developed databases (Rudolf A. et al., 2022).

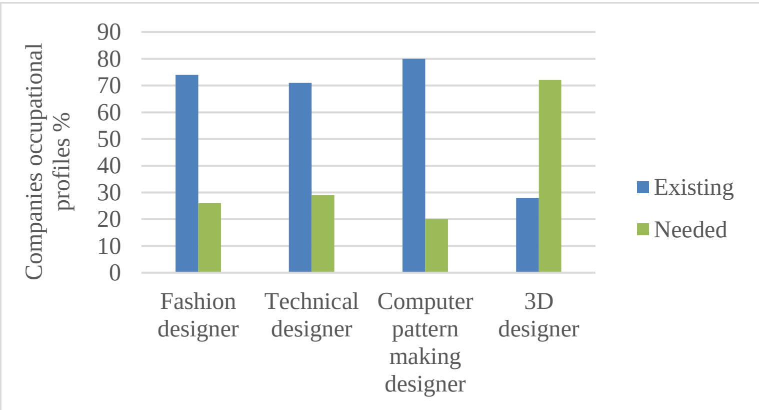



*Figure 1: Existing and required professional profiles in the field of garment design*

The creation of the knowledge databases was the second result of the Digital Fashion project. The 3D garment database was created using four selected garments (men's shirt, men's trousers, women's blouse, women's skirt) collected by the project partners. Each project partner provided patterns for a women’s skirt, a women’s blouse, men’s trousers and a men’s shirt. The database contains patterns for 10 different skirts, 10 blouses, 5 shirts and 8 men’s trousers. In addition, 2 men’s polo shirts, 1 pair of men’s shorts, 1 pair of men’s sweatpants and 1 men’s T-shirt have been added to the database. The patterns for the garments were graded into different sizes. The 3D human database comes from HOGENT’s Smartfit database. Smartfit is a national measurement study conducted in Belgium. The database contains the body measurements of more than 5000 Belgian men and women between the ages of 3 and 85. Avatars of young women aged 18 to 25 in sizes 38, 42 and 46 were chosen for the DigitalFashion project. The fabric database contains 49 physical textiles, both woven and knitted, while each partner provided at least two textiles commonly used for the selected garments and their respective styles. The structural, physical and visual parameters of the fabrics were determined on the basis of known textile standards, as was the drapability of the fabrics using the Cusick Drape Tester. The drape coefficients (DC), the number of nodes, the amplitude and the length of the nodes were calculated using the Drape Analyser software. In addition, orthogonal projections of the drape of the textiles were recorded with a digital camera, allowing the 49 fabrics to be digitised, Figure 2. The entire process comprises for digitising the fabrics have three main steps:

- Step 1 (estimation of drape parameters): A drape image of a real fabric is processed, and five drape parameters (explained in the next section) of the real fabric are estimated by extracting information from the image using image processing techniques,
- Step 2 (Clustering): The digital fabrics in the Lectra database are categorised into different groups based on their drape parameters and the number of nodes in the real fabrics
- Step 3 (Prediction): A series of machine learning classification models are applied to identify the closest digital fabric based on the results of Step 1 and 2 and the weight of the real fabric,

and is described exactly in the paper (Odhiambo S., et al., 2024).

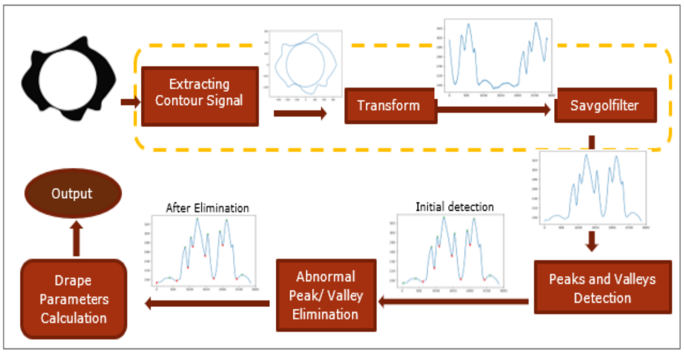
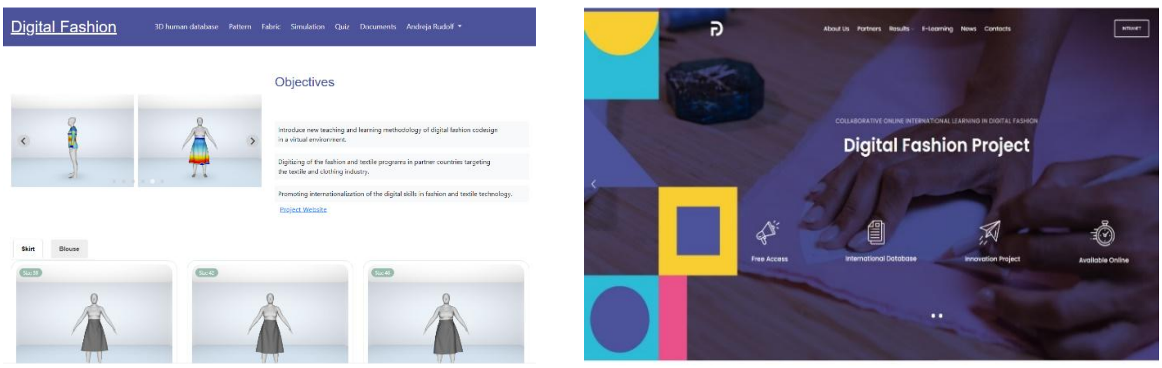



*Figure 2: The process of drape parameters estimation*

The development of the Digital Fashion platform was the third project result and can be found on this link [https://digitalfashion.ensait.fr/](https://digitalfashion.ensait.fr/). The homepage displays platform’s functions and data, Figure 3(a). The displayed content includes three parts:

- Objectives: This section contains the purpose and vision of the platform and prompts the site visitor to find all project results and info on the website [http://digitalfashionproject.eu/](http://digitalfashionproject.eu/), Figure 3(b).
- Garment Images: This section is about the displaying the garment database, including two types of garments (women blouse and skirt).
- Fabric Images: In this section you will find the fabric database, with 49 fabrics with different appearances and styles.




*(a)* *(b)*

*Figure 3: Digital Fashion project platform (a) and Digital Fashion project website (b)*

In the menu bar it can be find buttons for accessing databases:

- 3D human database, which contains 3D and 2D avatar images of women aged 18 to 25 years in sizes 38, 42 and 46, Figure 4(a), as well as information on the avatars’ body measurements according to ISO 8559:1989 + EN 13402-1:2001. The length measurements are based on an average height of 166 cm.

- The pattern database contains the data of blouse and skirt patterns, including name, style and technical drawing, Figure 4(b).
- The fabric database consists of a total of 49 fabric samples (F1-F49) for the design of 8 garments (two men's shirts, two men's trousers, two women's blouses and two women's skirts), Figure 4(c). The fabric parameters include the fabric appearance and all determined properties of the physical fabrics and the digital twins of the fabrics used to simulate the garments.
- Simulation: The function of this section is to simulate the e-shopping process. In this process, users can independently select avatars, fabrics and patterns. Finally, a virtual try-on model is created based on the user's selection, Figure 4(d).
- Documents: This feature contains the fourth set of project results, i.e. learning materials such as fashion database, fabric database, garment database (design cases, 2D garment design, 3D garment design, garment e-shopping, platform user guide), which are also available on the Moodle online teaching/learning platform (https://www.advan2tex.eu/portal/).
- Quiz with which learners can assess the level of acquired knowledge of the individual learning materials.

Each project partner produced one of the teaching materials. The University of Maribor was responsible for the Fashion database. We therefore present this learning chapter in more detail below.

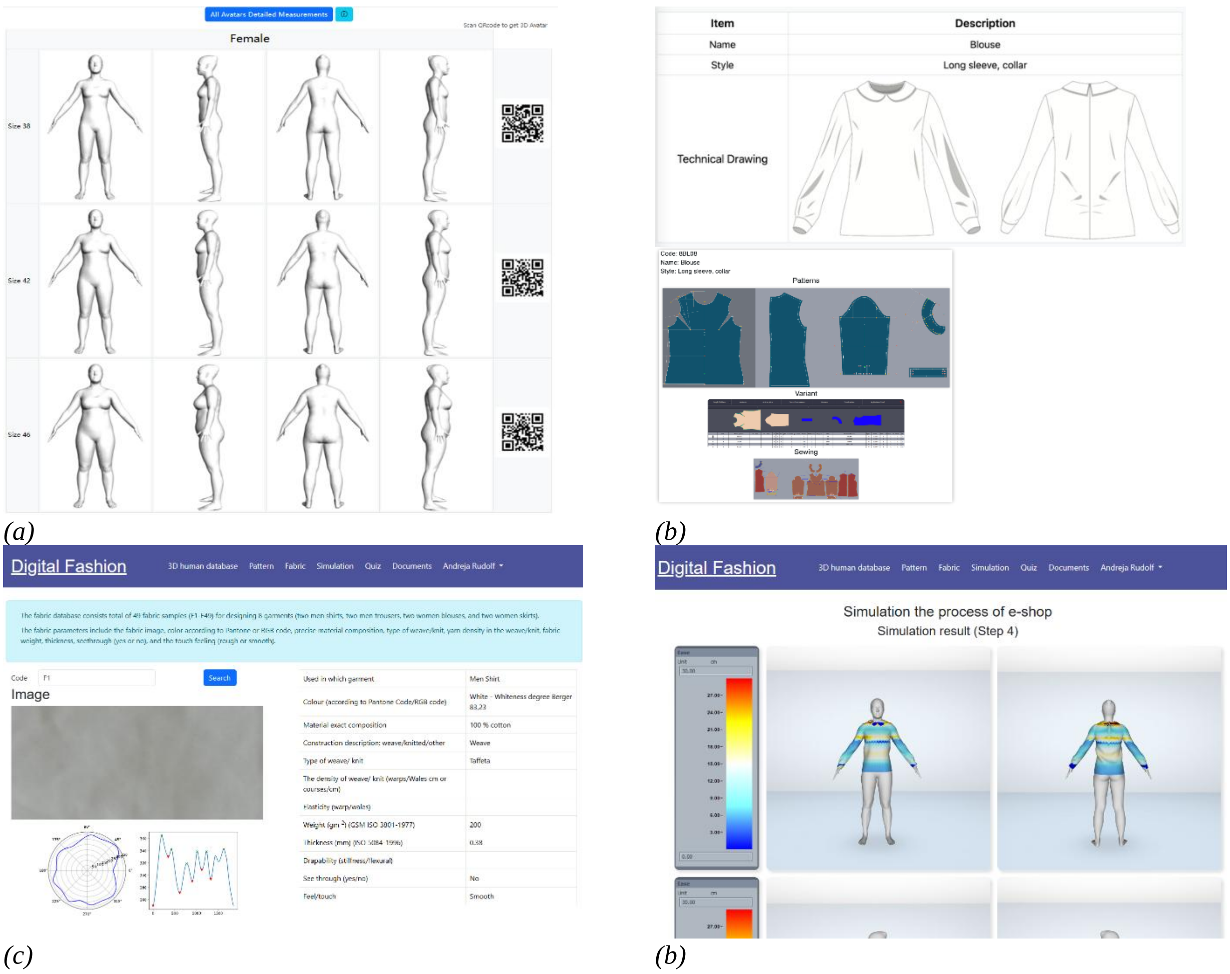



*Figure 4: Databases of the Digital Fashion platform: (a) 3D human database, (b) Patterns, (c) Fabric, (d) Simulations*

**FASHION DATABASE**

As fashion design increasingly combines creativity with technical precision, mastering digital tools is essential for future designers. The digital fashion technology platform provides a learning environment where fashion designers can use integrated knowledge databases to practise digital fashion design.

This chapter introduces the Fashion Database, which was developed to teach aspiring fashion designers the requirements of fashion and the basic design elements to support their creative and technical development in 3D fashion design. Fashion designers need to understand the basic elements and principles of garment design. To create garments that are visually intriguing and stand out from others, fashion designers must consider the four basic design elements of shape and form, line, colour and texture (Hopkins J., 2009) to acquire skills and use their experience to create their own concepts for designing of clothing.

Design elements serve as the basis for the development and design of all textiles and clothing products, including interior textiles. Throughout history, designers have used design elements in different ways to create aesthetics. Therefore, this chapter introduces the basic design elements of line, shape and form, colour and texture in more detail and shows where only these are considered and used in the design of clothing collections. The line is presented as the simplest and most important of the design elements, which is integrated into the other elements as defines the visual dimensions of lengths and widths of garments expressed by different types of lines, while when lines are combined, space is enclosed and shapes. The shape is presented as an external dimensions or contour of an object, e.g. design of garments often naturally reveals the shape of the human body, sometimes concealing it, but sometimes distorting it, while the human body is presented as a form that become visible from different perspectives. Colour is the first element to which the viewer reacts. It is the visual and essential element in fashion design and has aesthetic, visual and commercial value. Colour adds excitement, mood and evokes emotion to a design and therefore influences the overall look and feel of a design. To understand how colours interact with each other and how they can be used to evoke emotions and feelings, colour theory is represented: primary, secondary and tertiary colours, black colour, white colour, hue, shade, tint, tone and temperature of colour. It is also explained how we can match the colour combinations (analogous, complementary, monochromatic) of clothing with the colour wheel, which helps us to create a balanced clothing collection with a use of software such as Adobe Illustrator, CorelDraw, Photoshop, etc., which allows us to choose between RGB, Hex, CMYK, etc. colour palettes, Figure 5.

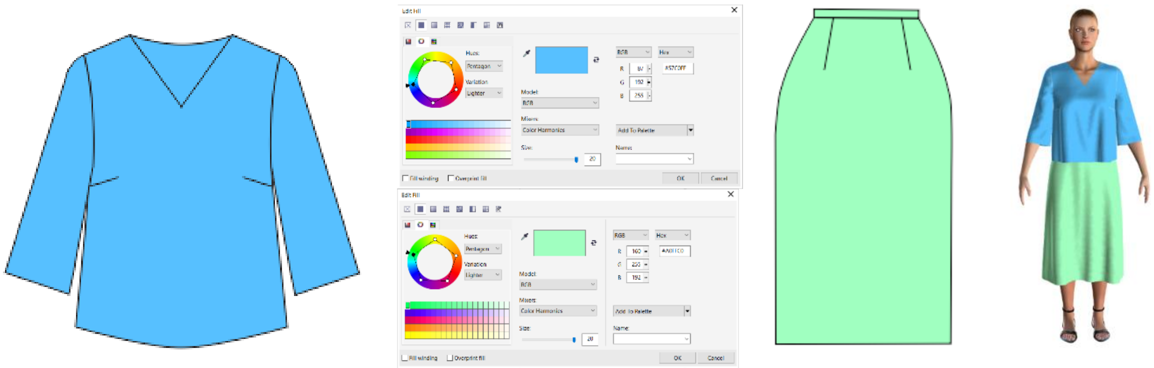


*Figure 5: Analogous color combinations.*

As described last, a texture is a design element that describes the look and feel of a surface that is perceived by both sight and touch. It is the quality of roughness or smoothness, dullness or lustre, stiffness or softness. Some words used to describe the texture of fabrics, such as rough, smooth, dull, shiny, firm, crisp, fluffy, voluminous, dull, etc., are represented by the use of a fabric samples.

At the end of the chapter, the basic design elements are combined using the example of a virtual 3D prototype of a clothing set, which provides a comprehensive insight into the field of digital clothing design, Figure 5.

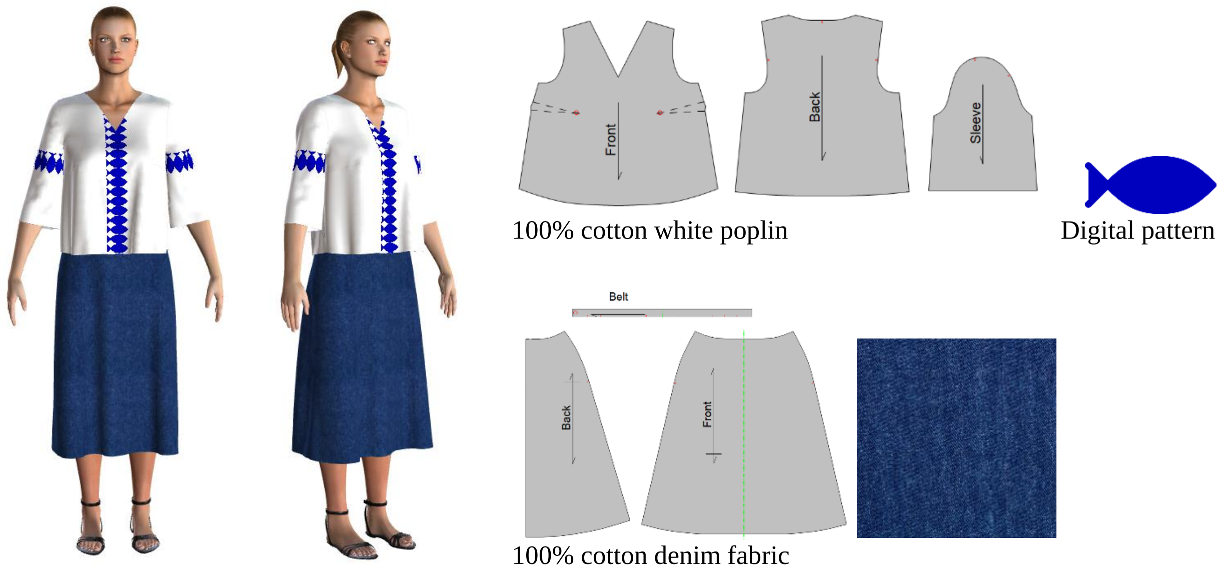



*Figure 5: Example of shape, form, line, colour and texture in virtual 3D prototypes of the blouse and skirt.*

## CONCLUSION

The Erasmus+ Digital Fashion project focuses on the development of an innovative platform that combines creativity with technical expertise. This platform, supported by comprehensive knowledge databases covering key elements such as fabrics, 3D body models, garments and 3D garment simulations, will enable designers to master digital fashion design. By fostering a deeper understanding of garment basic design elements and virtual 3D garment prototypes, traditional fashion principles are linked to modern digital tools, promoting both learning and development of fashion design in a technology-driven era.

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# THE IMPACT OF 3D DESIGN AND VIRTUAL SIMULATION IN GARMENT CREATION

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**ABSTRACT**

Pattern design for clothing, its production, and marketing have all seen radical changes thanks to the adoption of CAD (computer-aided design) software by the apparel industries. The CAD system's significance has grown since the fashion industry changes constantly due to quick shifts in consumer preferences and technology development. These systems are essential resources for contemporary clothing producers because they increase output and design accuracy and drastically cut costs and time-to-market. So, in the modern industrialized business, the use of CAD in all types of industries is noticeable, whereas, in the textile and apparel industry is categorized as CAD for fabric design, CAD for apparel design, CAD for pattern making, CAD for cutting room operations etc. This study aims to assess and present the importance of CAD software applications, related to pattern and marker creation, prototyping, and virtual simulation of clothing and fittings.

**Keywords**: CAD system, 3D patterns, simulations, productivity, cost-effective

## INTRODUCTION

In recent years, the fashion industry has seen a paradigm shift from traditional production, to retailer-driven production, to consumer-driven small-scale modern (fast fashion) production (Akhtar, *et al*., 2022). This industry is known for its unpredictable demand-supply relationships, long production times, short fashion results, raw material selection, seasonal demands, and heterogeneity (Huang & Rust, 2020). Therefore, mass adaptation to these industry trends requires quick responses and fast delivery. In particular, the quick response to the rapidly changing needs of consumers is considered one of the basic conditions for the success of companies in many industrial sectors (Wang, *et al*., 2021; Rincon-Guevara, *et al*., 2020; Wu, *et al*., 2020). So, advances in digital technology, from artificial intelligence, robotics and agile manufacturing, e-commerce, and social media, are becoming key drivers of growth in the fashion industry. The massive transformation of the clothing sector has also occurred due to the rapid technological advancement of the industry (Souza, *et al*., 2022). This industrial revolution will further shorten the time needed to launch new products, provide more affordable prices, more flexible production lines, increased productivity, and better utilization of resources (materials, time, energy, and labour) (Wijewardhana, *et al*., 2020; Ögülmüs, *et al*., 2015).

Computer-aided design (CAD) was originally developed as an interactive computer-aided system for the textile industry, then introduced to the apparel industry for pattern making and grading, and further developed for fashion and apparel design. Using a CAD system, the designer aims to minimize the use of paper or cardboard for cutting parts and markers, because now, the pattern has become a digital archive (Singh & Singh, 2017). In particular, the creation of markers is realized in just a few minutes. Recent technology platforms also allow greater flexibility in reducing waste, increasing cutting room efficiency and accuracy and creating accurate samples in time to reduce costs.

Pattern making is to fashion what architecture is to construction. It is an essential procedure, which involves the design and creation of garment patterns that are usually made from pieces of two-dimensional (2D) shapes that are traced onto the fabric for cutting (Zhang, 2017).

The work of pattern-making connects fashion design and garment making. It is considered the highest technical work in the process of designing and manufacturing clothes (LIU, *et al*., 2017). Currently, pattern-making still relies heavily on the experience of pattern-makers. There are two ways to make a clothing pattern: the traditional manual approach and a computer-aided process, both of which require sophisticated skills and experience (Gu, *et al*., 2016).

Currently, state-of-the-art 2D/3D computer-aided garment design software systems are intensively developed and applied as a powerful tool to facilitate the improvement of the pattern design process (Liu, *et al*., 2017). The innovations of 3D technology and computer graphs have transformed the way apparel is designed (Spahiu, *et al*., 2014). Especially, the possibility for the creation of three-dimensional models, which can be viewed in different directions, was particularly impressive (Dwivedi & Dwivedi, 2013). Although the fashion product development cycle and costs have been significantly reduced with the support of new solutions, the design of high-quality personalized tailoring that meets the demands of mass customization of clothing remains a knowledge and experience-intensive task in the fashion industry. Offering the designer, a virtual prototyping system has been an active area of research for many years. Despite being applied in other commercial industries, the development of 3D imaging for use in the apparel industry has faced many research challenges.

Due to all the mentioned benefits, the use of CAD software is the subject of numerous research studies around the world (Monika & Hooda, 2023; Sabina, *et al*., 2014; Jankoska & Stevkovska Stojanovska, 2024). So, using completely functional CAD tools, designers can create or modify patterns to meet their or customers specific requirements (Jankoska, 2020; 2021; 2022; Jankoska & Petreska, 2019; 2020; Jankoska & Stevkovska Stojanovska, 2023; 2024). With the use of this software, it is possible to apply not only a standard mannequin but also models created according to the appropriate body dimensions, which is inherent in the creation of custom-made clothing (Ondogan & Erdogan, 2006). The so-called virtual prototype solutions have gained importance in recent years because it is more precise, the clothes correspond to the measurements of the body, but also to the properties of the textile (Jevsnik, et al., 2012).

The aim of this study is to present the application of CAD software and its possibilities and benefits for the garment industry, through examples realized in DC Suite 3D fashion design software.

## EXPERIMENTAL PART

A clothing item's aesthetic appearance is evaluated through its appearance and the harmonious connection of all its components, such as material, color, cut, shape, dimensions, and decorative details. When creating and shaping the item of clothing, the functionality of the item should also be satisfied in terms of its purpose and type, because each piece of clothing has its specific characteristics of comfort when worn. Comfort in clothing comes from a good pattern (cut), which adapts to changes following the natural laws of body movement, which implements knowledge of human anatomy.

This paper uses DC Suite 3D, specific apparel CAD/CAM computer software for garment designing. The first step in garment creation is design and pattern making, which today can be realized using computer tools. So, this software can fully meet many design needs, like fashion design, textile selection, pattern creation, adjustment and modification, fitting, and virtual prototyping. Thus, with the help of this software (as well as others in this category), the following activities can be carried out:

- Construction of basic patterns for various types of models (2D)
- Modeling of basic patterns and their grading
- Transfer and positioning of 2D patterns in 3D

- Virtual sewing
- Simulation and fitting of ready-to-wear garments on avatars with appropriate body dimensions (can be taken from the software archive or adjusted by the designers according to the customer needs).

## RESULTS AND DISCUSSION

The basic role of this software is 2D pattern creation and 3D model (Fig. 1). He provides fast production of quality and precise cuts, adding seams and other details needed for tailor-made or mass production, like marks for buttonholes, button location, pockets, etc. (Fig. 2). The design is seamless, it can be modified if needed and added darts or pleats in record time.

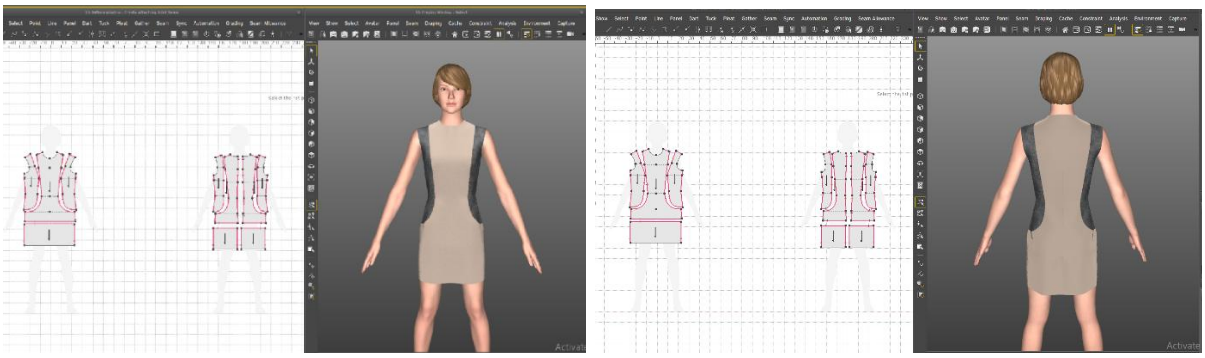

*Figure 1: Women's dress with leather detail, 2D patterns, and 3D model*

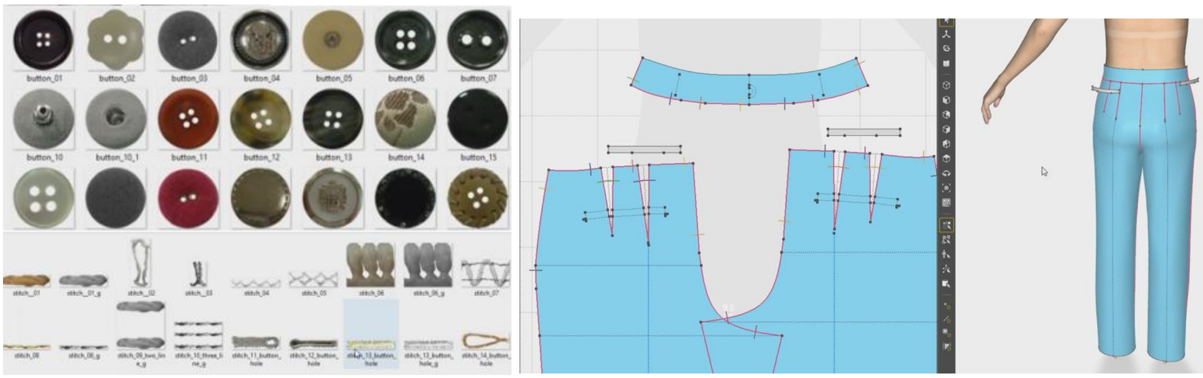

*Figure 2: Choice of button and thread and pocket position*

In the meantime, the garment should fit industrial sizing tables adapted to the target customer population, grading of the patterns is also provided. It should be pointed out that these operations realized in CAD software, make the process much faster and more precise (compared to manual work, which is labor-intensive and time-consuming), the same time allowing improved productivity and keeping up with the fast fashion (Arroyo, 2011; Naznin, Tabraz, & Sultana, 2017).

The virtual sewing can be performed with a transfer of 2D patterns in the 3D window, (Fig. 3). By stimulating the synchronization command, as the primary step to wrap the templates on the 3D model, all the patterns will be placed around the 3D virtual body avatar. Therefore, to simulate the fit of the clothes, virtual sewing of all 2D parts should be selected. This means that the sewing lines on the borders of the patterns are defined.

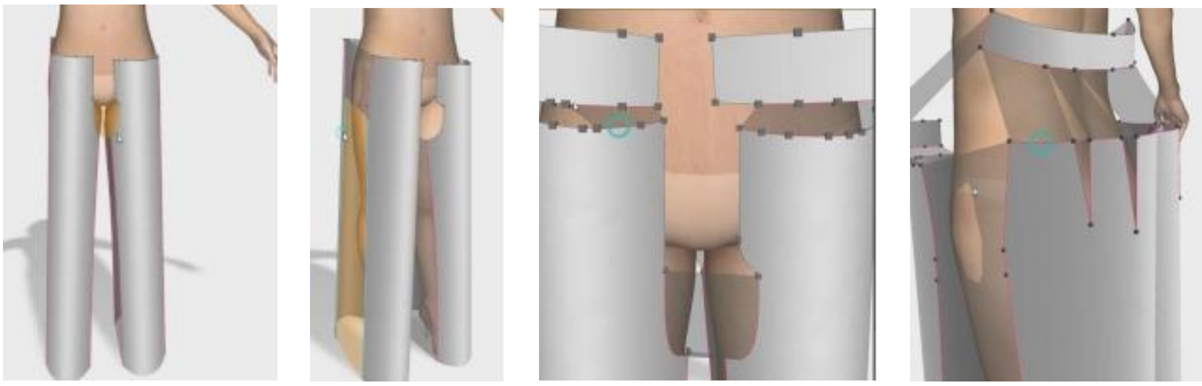

*Figure 3: Virtual sewing of the front with the back pants patterns and Example of sewing a belt*

Another benefit and opportunity the software provides is pattern storage in a digital format, for easy access and reuse in the future. This ability saves time and at the same time can be easily distributed or revised. Marker production is efficient (minimal waste and maximal use of the fabrics), since the software provides optimal arrangement of the patterns.

Since 2D design offers pattern development and technical sketches, 3D design provides an additional view of how the garment will look and fit on the human body, using 3D different virtual avatars (Fig. 4, and 5) instead of physical ones. Also, designers can visualize the garment in a real context by 3D modeling and evaluate how it drapes and wraps around the body. So, they can identify potential design weaknesses or defects before production starts or incorrect joining of different sides of the parts of the garment during sewing (Fig. 6). This leads to a better design process and improves communication between involved parties, as visual representations of sketch ideas are expressed more effectively than traditional prototype realization.

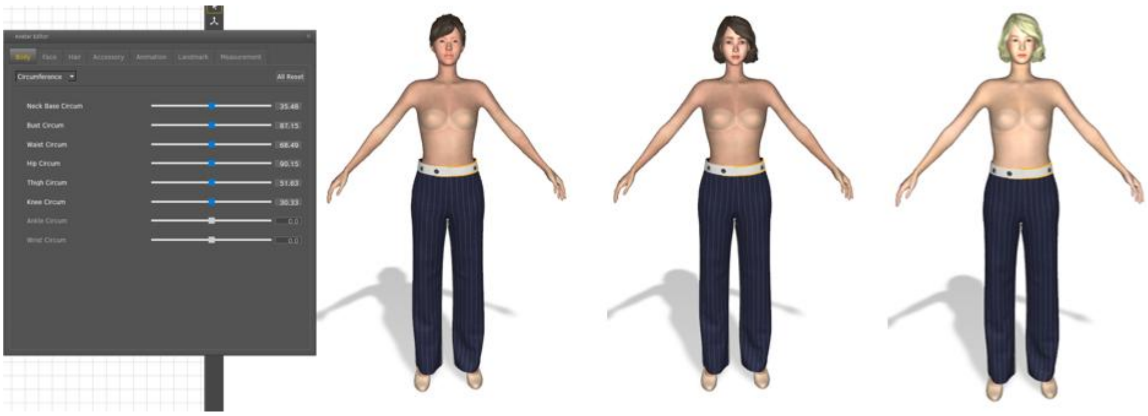

*Figure 4: Women's pants set on different avatars (virtual mannequins)*

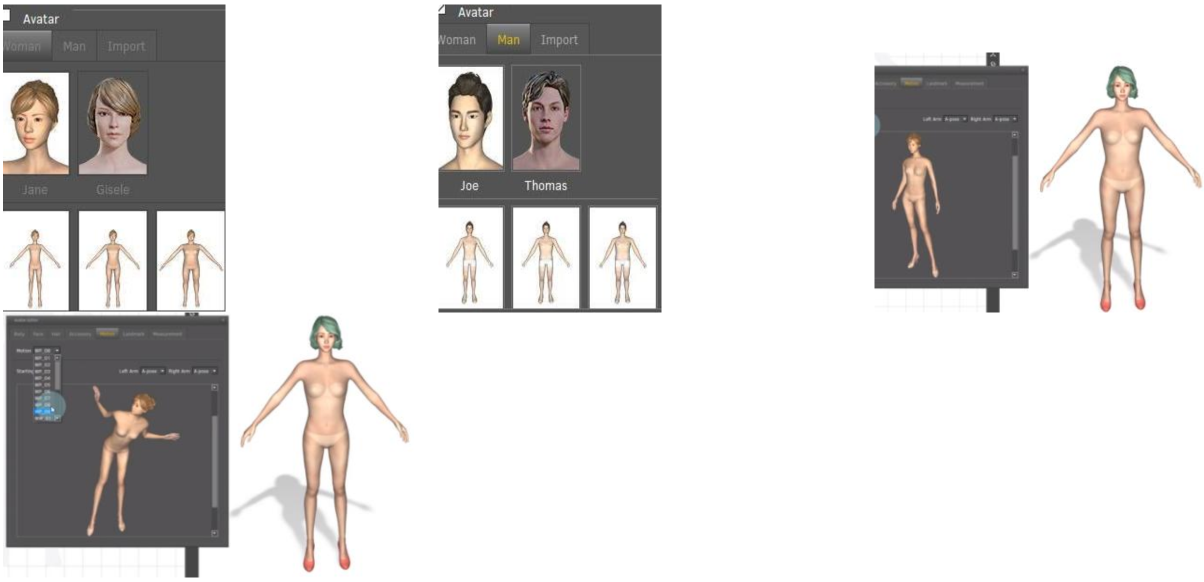


*Figure 5: Possibility to choose and adjust the avatar type*

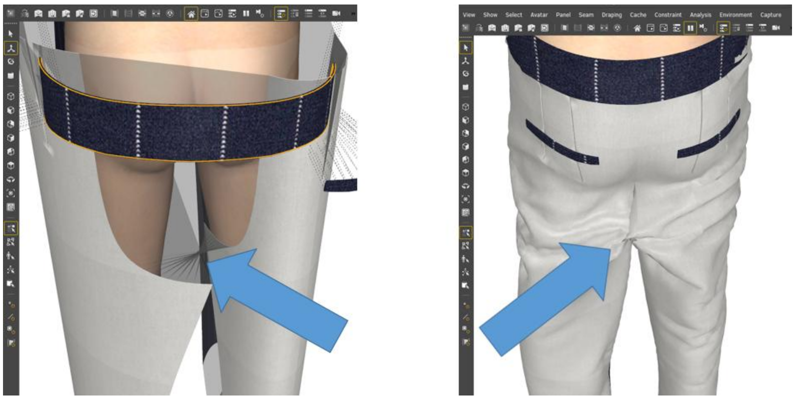

*Figure 6: Error in sewing direction and result in the final garment*

Fabric simulations are possible to be made too. Information for their physical properties and visual look can be added to the software, so selection can be made (Fig. 7 and 8).

*Figure 7: Women’s pants, one model type with different fabrics and material stripe settings*

*Figure 8: Women's dress, one model type with different fabrics*

With 3D CAD, a virtual model with clothes can be simulated, with a view from all sides and the possibility of rotation up to 360º (Fig. 9), (DC Suite 3D). It is also possible to determine the points where the clothes exert pressure on the body if they are not suitable. So, the fit assessment can be realized from all positions.

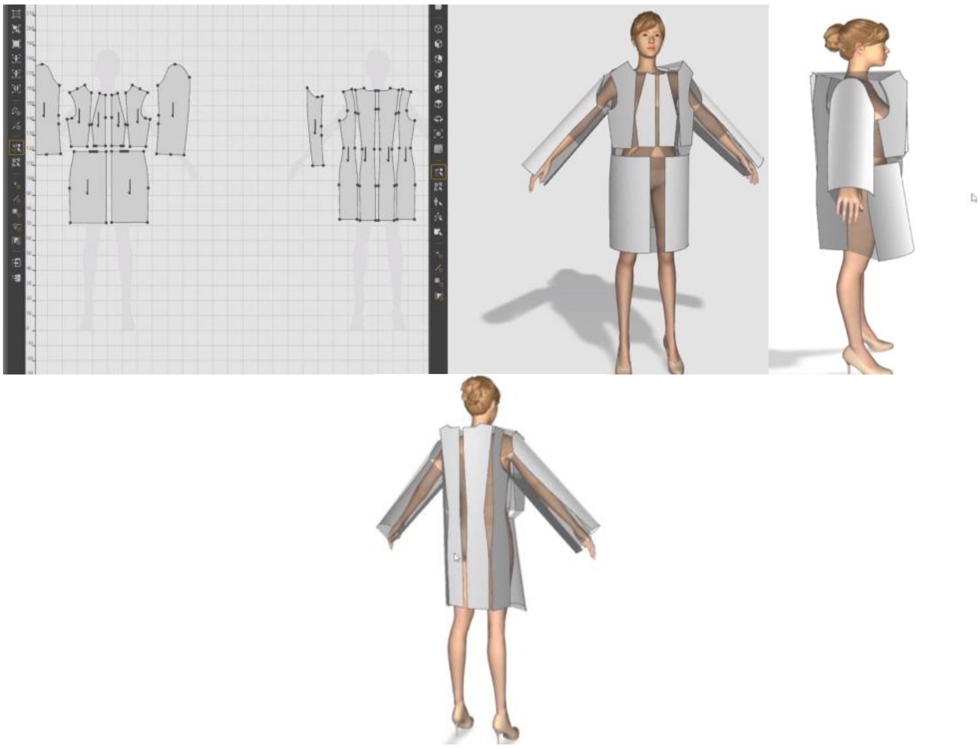

*Figure 9: Women's dress on avatars on different sides*

This software can accurately present the materials for the fabric simulation. Many fine details (like textures, stitches, embroidered details, and logos) and colors can be presented and created on the fabric (Fig. 10).


*Figure 10: Different embroidered details and their settings (rotation, translation, size)*

## CONCLUSION

Fashion design gives soul to clothing products and is probably the most fundamental yet critical process in the fashion supply chain. In the era of fast fashion, manufacturers must think of the most efficient way to design and produce clothing. Thus, to reduce time and costs, and improve productivity and precision, new technologies play a key role. This DC Suite 3D, CAD software allows designers to accurately plan, create, and model products before they are manufactured. That is, the possibility of establishing a virtual simulation using avatars excludes the need for the realization of physical prototypes. This is especially important when developing new products because inadequate products are something that businesses cannot afford. Certainly, having the ability to experiment with colors, patterns, and textures without creating physical samples is a flexibility that enhances creativity and leads to faster decision-making processes.

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# THE HARMFUL EFFECTS OF NOISE POLLUTION IN URBAN LIFE AND THE IMPACT OF VARIOUS TEXTILE STRUCTURES ON SOUND ABSORPTION

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## ABSTRACT

Noise pollution in urban environments poses significant health and comfort challenges. Long-term exposure to high noise levels can result in hearing loss, sleep disturbances, cardiovascular diseases, and psycho-physiological disorders. This paper explores the harmful effects of noise pollution and the role of textile structures in sound absorption. Various synthetic fibers, particularly polyester, exhibit strong acoustic properties, especially in the mid-to-high frequency ranges. Sound absorption efficiency is influenced by fiber type, density, structure, and weaving type. Composite materials incorporating polyester with other fibers demonstrate enhanced performance across a wide frequency spectrum, making them ideal for noise control in environments such as offices, music halls, and industrial settings. Woven fabrics, particularly honeycomb weaves, show superior sound absorption compared to plain weaves, highlighting the importance of structural design in acoustic applications. This paper reviews both the adverse effects of urban noise pollution and the potential of textile innovations to mitigate these effects, contributing to enhanced acoustic comfort in urban living spaces.

**Keywords:** Noise pollution, Noise, Sound Absorption, Textile, Fabric, Curtain

## INTRODUCTION

The longitudinal waves in the air create sound. The phrase can also refer to comparable vibrations across various mediums. Particle velocity is another useful characteristic for graphical display. According to the inverse square law, given a point source of waves that may radiate omnidirectionally and has no barriers in its path, the intensity diminishes with the square of the distance, from the source. The Doppler effect is the perceived shift in frequency of a heard sound when the source and observer move relative to one another. The amount of complete waves that are sent or received in a second is the definition of frequency for each wave. The ear drum, also called as tympanum, is a thin membrane that moves according to sound wave pressures, and it is joined to a chain of bones known as the ossicles. Resonances can form between two parallel surfaces when their distance is an odd number of half-wavelengths. Excessively loud noises can cause hearing loss. Psychoacoustics refers to the sometimes-ambiguous relationship between the physical qualities of sound and the brain's psychological perception of them (Talbot-Smith, 1993).

In this review article, a literature study has been conducted, examining the nature of sound and the process of hearing. The sound absorption capabilities of various materials have been explored, and a range of sound absorption methods have been compiled. Furthermore, methodologies with diverse applications that enhance sound absorption have been presented. The primary objective of this review is to provide a comprehensive overview of sound, discuss its potential harmful effects, and examine possible sound absorption methods. Particular attention is given to how everyday products, such as curtains, can be utilized to improve sound absorption, thereby enhancing comfort parameters.

## HUMAN EAR ANATOMY

The human ear is anatomically divided into three primary sections: the outer ear, middle ear, and inner ear, each serving a distinct function in the auditory process. High-frequency sounds induce maximal membrane motion near the cochlea’s base, while low-frequency sounds affect the apex. Situated atop this membrane are thousands of hair cells connected to nerves. Bending of these hair cells due to membrane motion triggers neural signals to the brain. Damage to these cells, whether partial or complete, results in impaired signal transmission and irreversible hearing loss, as these microscopic structures lack regenerative capacity (Baker, 1997).

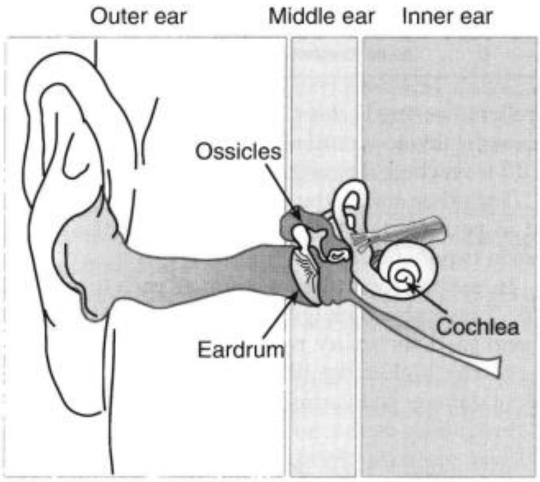


*Figure 7.Different Parts of Human Ear (Baker, 1997)*

Sound, an imperceptible yet forceful phenomenon and as mentioned before, it is characterized by intensity, frequency, and duration. Intensity, or loudness, is measured in decibels (dB), with human hearing ranging from 0 dB (the threshold of hearing) to 140 dB (the threshold of pain). The dBA scale, reflecting potential auditory damage, assigns higher values to more harmful noise levels. Frequency, measured in hertz (Hz), denotes the number of sound waves passing a point per second. The human voice spans approximately 200 to 4,000 Hz, and noise-induced hearing loss typically first affects the ability to discern higher frequencies. Duration of exposure to noise also critically influences the risk of hearing damage. For instance, safe exposure to 90 dBA noise is limited to eight hours per day, whereas exposure to 115 dBA is permissible for only 15 minutes. Each 5 dB enhancement above 90 dBA halves the safe exposure time. Consequently, preventing noise-induced hearing loss, which is irreversible and minimally alleviated by hearing aids, is paramount, underscoring the necessity of adhering to established exposure limits and implementing protective measures (Baker, 1997).

## HARMFUL EFFECTS OF NOISE POLLUTION

Consequently, noise pollution can lead to hear loss and other sound related issues such as lack of comfort and mental clarity. Throughout the expansion of urbanization and transportation, noise pollution was often regarded as a minor inconvenience rather than a critical issue. Presently, it is acknowledged that noise profoundly affects work efficiency and quality of life. As mentioned before, noise pollution is associated with various health concerns, including hearing impairment. Also, sleep disturbances, fatigue, cardiovascular diseases, and psycho-physiological disorders. In recent years, psychoacoustics, the study of how noise is subjectively perceived, has attracted considerable attention due to growing governmental awareness and public demand for noise reduction (European Acoustics Association, 2005).

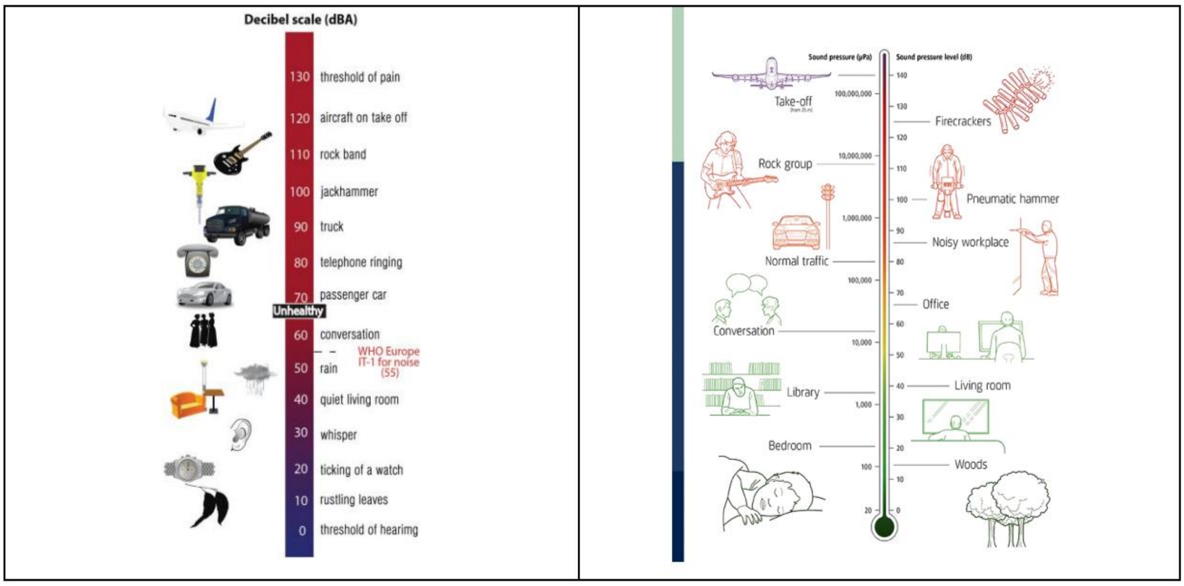


*Figure 8. Decibel Scale of Various Sound Sources (Simion et al., 1997)*

The transmission of sounds varies between environments, and the irritating impact is controlled by the frequency range of the noise. Thus, we may divide frequency range into three primary categories as follows:

• High frequencies range from 5000 Hz to 20000 Hz.
• Medium frequencies (100 Hz to 5000 Hz) are the most common and uncomfortable for human ears.
• Low frequencies (between 20 Hz and 100 Hz) (Simion et al., 1997).

As urbanization and transportation progressed, noise pollution was dismissed as an inconvenient but minor inconvenience. Currently, the general public understands that noise not only has a substantial impact on job efficiency and living standards, but it may also cause a variety of health issues such as hearing loss, sleep difficulties, fatigue, cardiovascular and psychophysiologic disorders, and so on (Marquis-Favre et al., 2005a, 2005b). Accordingly, it is critical to manage noise in residential areas.

**SOUND – ABSORBING MATERIALS**

Using fiber sound-absorbing substances to absorb sound wave energy is an essential strategy for reducing the consequences of noise pollution (Cao et al., 2018). Additionally, sound-absorbing materials could increase acoustic comfort (for example, speech intelligibility) by reducing reverberation duration in workplaces, music halls, exposition halls, opera houses, and so on(Na et al., 2007).

Fibrous materials are important in the building sector because they act as both sound and heat insulators. Some classic fibrous insulators, such as glass fiber and mineral wool, are extensively used in sound absorption tasks because of their large specific surface area, strong acoustical performance, and low cost (Yang et al., 2018).

*Table 2. Different Synthetic Fiber's Absorbtion Values (Radzi et al., 2021)*

| Synthetic fibre | α High frequencies, Hz | α Low frequencies, Hz |
|---|---|---|
| Inorganic fiberglass | 1.00 (4000 Hz) | 0.51 (1000 Hz) |
| Polymer foam is mixed with natural fibers | 0.999 (5000 Hz) | 0.83 (1000 Hz) |
| Polyester fiber | 0.91 (6000 Hz) | 0.65 (1500 Hz) |
| Polyurethane foam is mixed with Electrospun Nylon-6 Nanofibre Mat and Polyurethane | 0.39 (4000 Hz) | 0.60 (1000 Hz) |
| Glass fiber mixed with flax fiber | - | 0.16 (2000 Hz) |
| Porous metal fiber material | 0.53 (6000 Hz) | 0.06 (1500 Hz) |
| Polyurethane foam is a mixture of textile residues | 0.42 (3100 Hz) | 0.87 (1000 Hz) |
| Polymer microparticles | - | 0.54 (1600 Hz) |
| Fiberglass installation with sandwich panel | 0.27 (5000 Hz) | 0.62 (1000 Hz) |
| Non-woven polyester fiber. | 0.88 (5650 Hz) | 0.8 (1125 Hz) |

The acoustical characteristics of porous sound absorbers may be characterized using a variety of methodologies, including the impedance tube method, the reverberation chamber method, the two-microphone free field method, and the in-situ method. One of the most often used method is the impedance tube approach (Radzi et al., 2021).

The sound absorption characteristics of synthetic fibers, particularly polyester, are substantially influenced by factors such as fiber type, structure, and weave. Polyester fibers, widely used for their acoustic properties, demonstrate high sound absorption, particularly in the mid to high-frequency ranges. For example, nonwoven fabrics made from 50% solid polyester and 50% hollow polyester fibers show optimal sound absorption in the mid-to-high frequency range, around 1000-4000 Hz, with the highest reduction occurring when fiber density is maximized (Devi, 2014). Polyester materials are particularly effective when structured with air gaps, which enhance their low-frequency performance. Composite nonwoven structures combining reclaimed polyester and cotton fibers also exhibit high sound absorption across a wide frequency spectrum (250Hz-2kHz), with reclaimed polyester composites showing superior sound reduction due to higher bulk density and lower porosity (Sakthivel et al., 2021). Additionally, woven and needle-punched nonwoven fabrics offer considerable sound absorption, with hollow conjugated polyester fibers providing superior performance due to their internal voids, which enhance sound dissipation (Paul et al., 2022). Polyester acoustic boards, constructed from multiple layers of polyester fibers, further enhance low-frequency absorption, especially below 500 Hz, making them ideal for noise control in diverse environments (Jun et al., 2020).

## SOUND ABSORPTION CAPABILITY OF VARIOUS MATERIALS

The impedance tube method is a recognized approach for quantifying the sound absorption capability of acoustic materials in accordance with the ISO 10534-2 regulation (Buratti et al., 2014; Chen et al., 2017) The specimen size required for measurement with an impedance tube is relatively tiny. Specimens of small diameter (≤30 mm dia.) are typically utilized for high frequency tests (>2000 Hz), whereas bigger diameter specimens (31 mm dia. – 100 mm dia.) are used for low frequency tests (≤2000 Hz). The impedance tube has a straight, smo–th, and airtight circular tube with the test specimen fixed at one end. A sound wave is created from a loudspeaker at the opposite end and directed towards the specimen.

There are 2 main approaches for measuring impedance tubes: the standing wave technique and the transfer function technique (Tie et al., 2020).

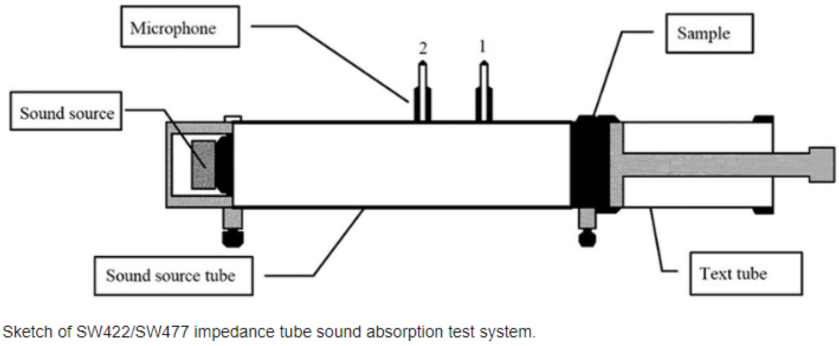


*Figure 9. Impedance Tupe (Lyu et al., 2020)*

Polyester, a widely used synthetic polymer, has also been investigated for its sound absorbency properties, particularly when utilized in fibrous forms. Similar to other synthetic polymers, its performance is evaluated through the sound absorption coefficient (α), which measures the efficiency of the material in dissipating sound energy across various frequencies. Polyester's inherent flexibility and ease of production make it an attractive option for sound-absorbing applications, especially when it is processed into fibrous panels or combined with other materials to enhance its acoustic properties.

Polyester fibers, in particular, are known for their effective sound absorption in the mid-to-high frequency ranges. Studies by Zulkifli et al. (2010) found that polyester fiber panels exhibit absorption coefficients of 0.70 at 2000 Hz, which is comparable to other high-performance materials like polyurethane foam. These panels are often used in building acoustics and automotive interiors where reducing airborne noise is crucial. The study also showed that increasing the thickness and density of polyester fiber panels improves their performance, especially at higher frequencies (above 1000 Hz). Moreover, the combination of polyester with other materials, such as polyurethane, has been shown to enhance sound absorption further, making it more versatile for a wider range of applications (Zulkifli et al., 2010).

Polyester's sound absorption capabilities can be significantly improved through composite formulations. Al-Homoud (2005) demonstrated that polyester, when combined with natural fibers like cotton or coir, results in composites that perform well across both low and high-frequency ranges. For instance, a polyester-natural fiber composite achieved sound absorption coefficients of 0.65 at 500 Hz, demonstrating its effectiveness in applications requiring low-frequency noise reduction. These composites also offer an eco-friendly alternative to fully synthetic materials, aligning with the growing demand for sustainable building materials in acoustic engineering.

Compared to other synthetic polymers like polyurethane and polystyrene, polyester generally performs well in the mid-to-high frequency range but may require additional modifications to enhance its low-frequency absorption. For instance, the introduction of perforations or surface modifications can improve its overall acoustic performance. Wang et al. (2014) showed that perforated polyester composites reached absorption coefficients of 0.60 at 1000 Hz, similar to those observed in perforated PVC layers. This versatility, combined with its lightweight nature and ease of manufacturing, makes polyester a competitive option in various noise control applications, particularly where cost and sustainability are key considerations.

Polyurethane remains the top performer for high-frequency sound absorption, particularly in its foam form, with absorption coefficients regularly exceeding 0.75 at frequencies above 1000 Hz (Fatima and Mohanty, 2011). Polyester, while effective, is more frequently used in its fibrous form, and its performance can be enhanced with composites or structural modifications. In contrast, polystyrene and polyvinyl chloride (PVC) typically require composite formations or perforation techniques to match the absorption efficiency seen in polyurethane and polyester, especially at lower frequencies (Nakanishi et al., 2017; Wang et al., 2014).

In summary, polyester is a highly effective synthetic polymer for sound absorption, particularly when processed into fibers or combined with other materials in composite structures. Its performance in the mid-to-high frequency range makes it suitable for a variety of applications, although modifications are often needed to optimize its low-frequency absorbency. The comparison of polyester with other polymers such as polyurethane, polystyrene, and PVC highlights the strengths and limitations of each material, demonstrating that the selection of a polymer for sound absorption depends heavily on the specific frequency requirements of the application.

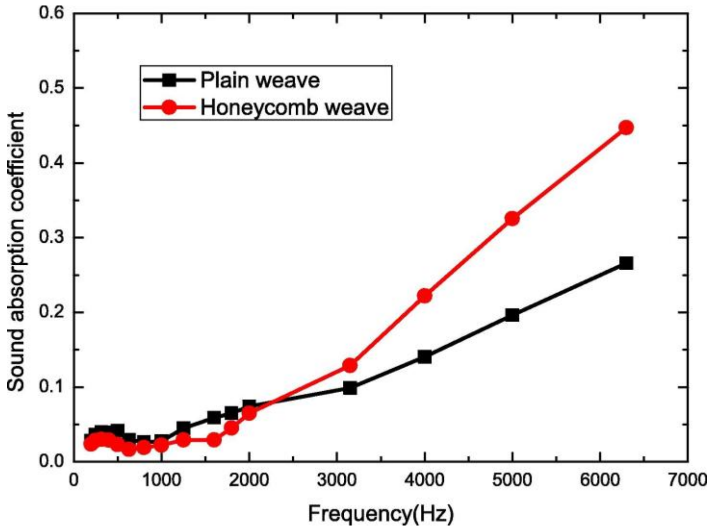


*Figure 10. Honeycomb and Plain Weave Comparision (Liu et al., 2021)*

When comparing honeycomb weaves and plain weaves in sound insulation, studies indicate that honeycomb weaves offer superior acoustic performance due to their unique structural characteristics. Honeycomb weaves, with their three-dimensional structure and larger surface area, provide better sound absorption, particularly in the low-frequency range. The cell patterns in honeycomb weaves, such as hexagonal or Kagome lattice, create internal voids that trap and diffuse sound waves more effectively, improving noise reduction coefficients (NRC) at both high and low frequencies (Yasin et al., 2014). In contrast, plain weaves, which have a simpler, two-dimensional interlacing pattern, exhibit lower sound absorption due to their limited ability to disrupt and diffuse sound waves. While plain weaves can be effective when used in combination with other materials or layered designs, their acoustic insulation is generally less efficient compared to honeycomb weaves (Liu et al., 2021). Therefore, honeycomb weaves are more suitable for applications requiring high sound insulation efficiency.

Also, there are various commercial curtain options for sound insulation. Commercial sound insulation curtains are an effective solution for reducing noise in various environments, such as offices, industrial sites, and hotels. These curtains are typically made from materials like mass-loaded vinyl and quilted fiberglass, which work together to block sound and improve acoustics. Options such as Steel Guard Safety's industrial sound curtains offer a sound transmission class (STC) rating of up to 33, while other brands like Quiet Curtains provide high noise reduction with customizable designs for different commercial needs. These curtains not only help reduce noise but also offer additional benefits like thermal insulation and privacy (eNoise Control, 2024; Steel Guard Safety, 2024; Saaria, 2024; Acoustic Curtains, 2024).

## CONCLUSION

Noise pollution in urban areas significantly impacts public health and well-being, causing hearing impairment, psychological stress, and reduced quality of life. Sound absorption through fibrous materials, particularly synthetic fibers like polyester, offers an effective solution to mitigate these harmful effects. Studies have shown that the structure, density, and composition of fabrics play a crucial role in their sound absorption performance. Nonwoven polyester fabrics, composite materials, and honeycomb weaves outperform traditional materials in reducing noise, especially in the mid-to-high frequency ranges. The use of advanced textile structures in building acoustics, workplaces, and public spaces can significantly reduce noise pollution, improve living conditions, and protect against long-term hearing damage. Further research into material modifications, sustainable alternatives, and industrial applications will enhance the development of effective noise reduction strategies in urban environments.

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# CONTAMINANTS IN TEXTILE RECYCLING – A LOOK AT COMMON HABERDASHERY AND FIBER BLENDS FOUND IN T-SHIRTS

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**ABSTRACT**

Sustainability and circularity have become increasingly important in the textile industry, driven by rising consumer awareness and policies demanding eco-friendly materials and manufacturing practices. The industry has responded by advancing textile recycling technologies and innovations in sorting used garments. However, the use of fiber-to-fiber recycling for new garments remains below 1 % globally. To increase this, the industry must address challenges such as improving collection infrastructure, enhancing sorting processes, and managing contaminants and fiber blends.
Contaminants, particularly haberdashery items like fasteners and trimmings, pose significant obstacles for recycling. Fiber blends, while beneficial for garment features, complicate recycling efforts. A market study on t-shirts from various brands was conducted to understand the common fiber blends and haberdashery utilized in this product group, providing insights into their suitability for current recycling technologies. Accordingly, the research provides valuable insights for the Ecodesign rules on clothing that is planned in the European Union and for apparel recycling in general.

**Key words**: textile recycling, contaminants, circularity, ecodesign, sustainability

## INTRODUCTION

The production of fibers is steadily increasing and is estimated to reach 149 million tons by the year 2030. Despite rising demands for more sustainable and recycled materials, only about 8.5 % of all fibers produced are made from recycled materials, of which only around 0.6 % originate from pre- and post-consumer textile waste. (Textile Exchange 2022) The EU thus wants to redirect the focus to fiber-to-fiber (F2F) recycling, aiming to keep fibers in circulation and close loops within the sector (European Commission 2022). Accomplishing this ambitious goal requires overcoming several challenges. For garments to be newly introduced into the market, sustainability improvements can already be integrated at the design phase, applying ecodesign guidelines. However, for garments already in use, other strategies are needed.

A key factor for economic and ecological viable F2F recycling is a consistent high-quality supply of feedstock. Given the highly heterogeneous nature of textile waste, this poses to be a great challenge. Technologies like Artificial Intelligence and Near Infra-Red Spectroscopy offer promising solutions by enabling more accurate sorting of textile waste e.g. by type of fiber and color, even detecting damage such as holes and haberdashery items. These technologies can help separate potential second-hand items from waste and improving the overall quality of the feedstock for recycling. Of course, these technologies are not without their flaws and challenges either and most still need to be applied in industry.

In this paper we take a closer look at the product group t-shirts, as they are one of the most popular types of garments and thus make up a large portion of the post-consumer textile waste. Gaining in-depth knowledge about their composition and contaminants will enable the development of effective ecodesign guidelines, allowing the industry to better recycle its waste and ideally closing loops in the process.

## THEORETICAL BACKGROUND

This section introduces the typical features of t-shirts, provides an overview of common textile recycling technologies, and highlights key contaminants in textile recycling to clarify the study's context.

### T-Shirts

As per the product classifications for import and export matters, the EU defines t-shirts as “a lightweight knitted or crocheted garment, of a vest type, of cotton or man-made fibre, […], with or without pockets, with long or short close fitting sleeves, without buttons or fastenings, without collar, without opening in the neckline” (European Commission, n.d.). Decorations such as prints and adornments other than lace are allowed, the hem of the t-shirt has to be without means of tightening or ribbing. Upperwear with fastenings like buttons or zippers made from knitted or crocheted fabrics fall under the category jerseys and pullover. (European Commission, n.d.).

This distinction is not generally made in the actual market. The term t-shirt is more commonly used for the cut and it can also be made out of lace or even woven fabrics. For this study, we consider all type of garments that the brands themselves label as t-shirts in their online shops, even if this includes garments that by definition would fall under the category jerseys, e.g. polo-shirts.

A typical t-shirts is made of knitted cotton fabric and depending on the cut, it might contain some content of elastane fibers. Generally, loose cut garments do not contain elastane, whereas tight or even body-con t-shirts contain rising numbers of elastane to improve the fit and comfort of the garment and allowing it to be worn without any means of closure. For t-shirts in the lower price segment of the market, parts of the cotton can get replaced by lower cost fibers such as polyester. T-shirts may or may not have adornments like prints, embroideries, patches, pearls or sequins as design and branding elements.

### Recycling Technologies

To date, there are several different textile recycling technologies available, reaching from lab-scale to being fully established. The most common and widely applied technology is **mechanical recycling**, where textiles get cut and shredded until their fibers remain. During this process, the fibers get damaged, resulting in shorter lengths, damaged cross-sections and uneven ends, leading to reduced strength and elasticity of the regained fibers. For the reuse in the garment production, 10 to 80 % of virgin fibers have to be blended with the recycled fibers to balance out the reduce properties. (Ribul et al., 2021; Ellen MacArthur, 2017) Beside elastane, which is difficult to rip and cut, any fiber blends can be mechanically recycled. However, for use in new garments, the fiber compositions need to be known in accordance with ingredient labelling requirements.

Another well-established process is the **thermo-mechanical recycling**. This process is mainly used in the packaging industry and can only be utilized for thermoplastic materials like Polyethylene Terephthalate (PET). The PET fibers are heated until liquification and can then further be used for a variety of different applications. (Pensupa, 2020) Only high quality and thoroughly sorted input streams are viable for this process, as contaminants can only be removed to such degree, making the application for textile products challenging. (Ribul et al., 2021)

Polymer recycling, also known as **solvent-based recycling** is a process, where selective solvents are utilized to dissolve certain fibers from the textile input. Other fibers present stay mainly unaffected by the process and can be reused separately. This process is suitable for fiber blends, especially for polyester-cotton. During this separation process, the polymers of the fibers remain intact, dissolve and can then be recovered from the solution. The quality of the polymers and fibers stays the same, though can be improved through additional steps. (Pensupa, 2020; Ribul et al., 2021)

One of the most promising textile recycling technologies in terms of fiber quality is **chemical monomer recycling.** This type of recycling technology breaks down the fibers into their monomers or oligomers by depolymerization and can be done by a variety of different methods, e.g. hydrolysis. Depending on the technique, different levels of purity are required for the textile input. The recovered monomers are of virgin quality and can be used in a variety of different applications, e.g. the manufacturing of PET fibers. This recycling technique is also applicable for blended textiles like polyester-cotton, though repolymerization of monomers is only possible for manmade polymers. Cellulose is depolymerized into e.g. glucose for use in different industries. (Pensupa, 2020)

Lastly, **biological recycling** is promising as well, though thus far only available on lab-scale. The depolymerization of polymers is done using natural means, such as enzymes or microorganisms. Similar to the chemical recycling, the recovery of monomers and oligomers is possible. Enzymes break down polymers selectively, meaning that each type of fiber requires certain enzymes for depolymerization, enabling the recycling of fiber blends. Regained monomers from PET are of virgin quality. (Ribul et al., 2021; Lee and Liew, 2021).

To achieve high quality output from the various textile recycling technologies that is both economical and ecologically feasible, a well sorted, mostly homogeneous input stream with little contaminants and different fiber types would be the ideal scenario. As this is not possible to obtain with the currently available technologies and used garments on the market, it is important to determine the most likely present contaminants and fiber blends for different product categories to provide insights into the input streams that recycling has to tackle. By understanding suitable input streams for various recycling technologies, this would support defining suitable ecodesign guidelines as well as improve the sorting and recycling technologies for higher quality output.

### Contaminants

Every material on a garment other than the main fibers could be described as a contaminant. This includes haberdashery items both for design and wearability, as well as dyes, finishings and prints. Additional fibers like elastane that are added e.g. for comfort are also to be regarded as contaminants, as they vary from the main material. Though usually only present in small quantities around 5 %, elastane poses great difficulties for recycling technologies. Contaminants are usually well anchored to the garment to achieve their intended practical purpose or to prevent them from detaching during the life cycle of the garment. This also makes the removal for recycling purposes difficult and large contaminants such as zippers and prints often have to be removed manually by cutting. For the composition of the different haberdashery items there is basically no limit. Buttons e.g. can be made from a variety of plastics but also from natural materials like mother of pearl or bone, making it difficult to predict the composition and compatibility of the garments and the recycling technologies. Especially metals pose to be of great risk during recycling processes as they might disrupt the chemical reactions or damage the machinery. A mixture of different types of plastics might also be an obstacle for depolymerization.

## METHOD

To determine the t-shirts currently on the market and thus likely being found in post-consumer textile waste collection in a few years, two of the ten most popular brands on the EU market have been randomly selected for closer examination of their product group t-shirts regarding fiber composition and visible contaminants. For the determination of the most popular brands in the EU, the statistic “The giants of large-scale distribution” from the Modaes.es (2023) report titled “El Mapa de la Moda 2023

Facts & Figures" has been used. The brands mentioned in the selected statistic are naturally ranked by decreasing revenue, thus their rank has been used correspondent to the numbers used as input on random.org. The random selection results in the brands H&M and Primark, which are 2nd and 6th in the polularity ranking.

To determine the utilized fiber types as well as haberdashery in the product group t-shirts, the currently available garments of said product group by each brand were analyzed. As turnover with female clothing is higher than with men's, to further limit this research, only garments marked as women's clothing were be analyzed. For the analyzation, the German version of both online shops have been observed in September 2024. The available garments have been filtered using the available filter-options of each online shop, the applied filters can be seen in Table 1. The total number of results from the search may include the individual listing of each available colorway of a garment. Few garments have been listed several times in the H&M online shop, resulting in 415 final t-shirts instead of the 434 initial results.

*Table 1: Applied search criteria for analyzed garments for the category t-shirts*

| Brand | Main Category | Additional Filters | No. of total Results | Notes |
|---|---|---|---|---|
| H&M | Women<br>Clothes<br>Tops & T-Shirts | T-Shirts | 415 (434 hits)<br>(01.09.2024) | Includes long sleeves, includes other brands |
| Primark | Women<br>Clothes<br>Tops & T-Shirts | *Not possible* | 203 (10.09.2024) | Includes Tops, long sleeves and bodies |

To document all the visible contaminants and fiber types of the analyzed garments, four different groups for documentation have been summarized: (a) fasteners, (b) adornments, (c) color and (d) fibers. The groups are then further divided into different types of said summarized group, resulting in a total of 17 possible fiber types and a total of 20 different contaminants, of which seven fasteners, ten adornments and three color. This allows us to gain an in-depth overview of the utilized materials and haberdashery in this product group and thus find the most popular of each selected group, providing a basis for future ecodesign recommendations for t-shirts. The information regarding the fiber composition of the garments cannot be tested for correctness in a lab during this research.

**FINDINGS**

A total of 618 garments have been analyzed for this study, of which 415 were manufactured or sold by H&M and 203 by Primark. As shown in Figure 1 the analysis results in a total of 294 garments made by a single type of fiber and 324 garments made of 77 different fibers blends distributed over both companies. Of those blends, only a total of eight blends have been used by both brands. The maximum of noted different fiber types blended together is three, of which 24 different 3-fiber-blends have been used, distributed over a total of 54 garments.

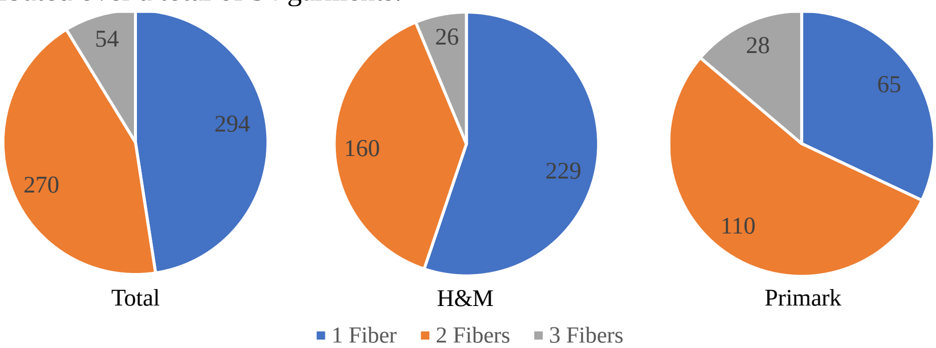


*Figure 1: Distribution of number of used fibers used in t-shirts by H&M and Primark*

To condense the 53 different 2-fiber-blends to blends with the same fiber types disregarding of the values of said fibers, we are left with 16 combinations. As showcased in Figure 2, the most utilized combination for blends made from 2 fibers is a cotton-elastane blend, followed by polyester-elastane and viscose-polyamide. Figure 2 also depicts the types of fiber that have been used for garments made from one fiber. Over 93 % of mono-fiber garments are made from cotton (CO).

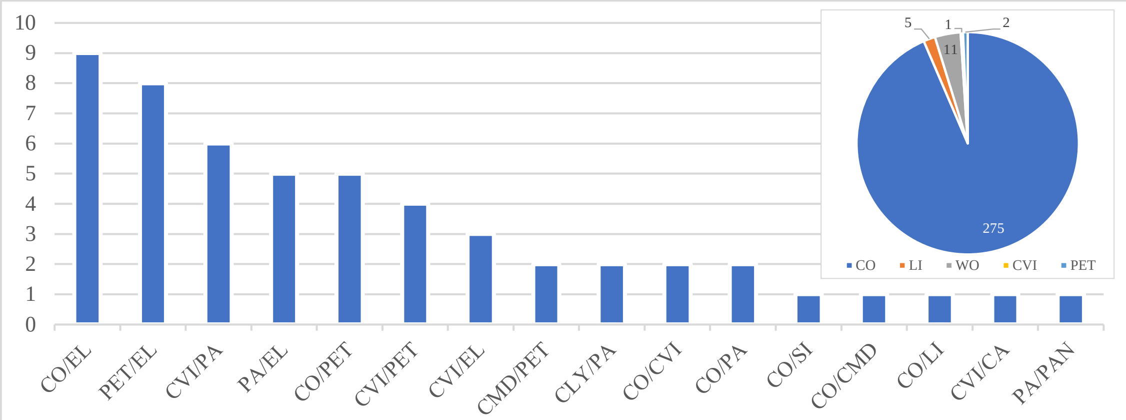


*Figure 2: Most popular fiber-combinations for t-shirts made from 2-fiber blends by H&M and Primark and type of fiber utilized for mono-fiber fabrics*

The most popular blends utilized are shown in Figure 3. The selected blends had to be utilized a minimum of five times in order to be included in the figure. For both brands, the most popular fiber and fiber blend are 100 % cotton with 211 and 64 garments respectively, followed by a blend of 95 % cotton and 5 % elastane (EL) with 40 and 45 garments. The following blends vary greatly in composition and value. Primark utilizes more viscose fiber blends, while H&M uses more blends containing cotton.

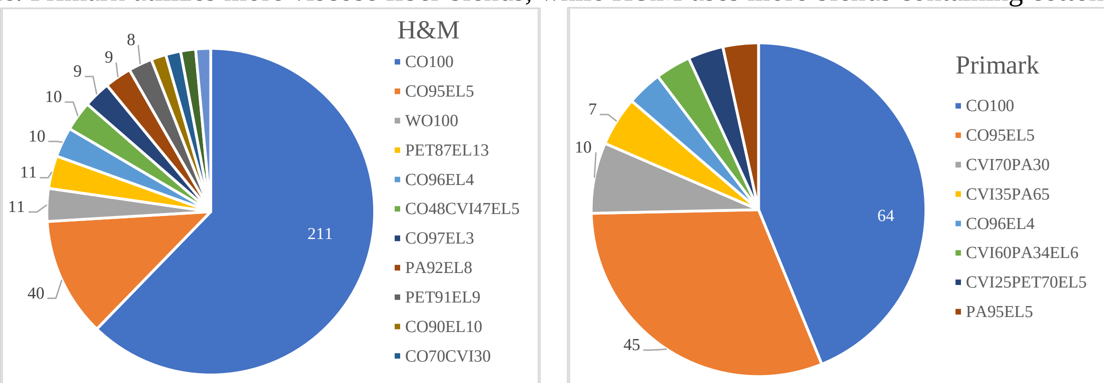


*Figure 3: Most utilized fibers and blends for t-shirts by H&M and Primark in pcs*

Figure 4 gives an overview for the number of times each fiber was used, whether alone or as a blend. Cotton has been used a total of 457 times, followed by elastane with a total of 251 times. Viscose (CVI) and polyester (PET) are also popular, being utilized a total of 98 and 82 times respectively. Figure 3 also showcases the different utilized elastane contents in the blends. The most popular elastane value present in over half of the garments containing elastane in a blend is 5 %, followed by values of 4 % and 6 %.

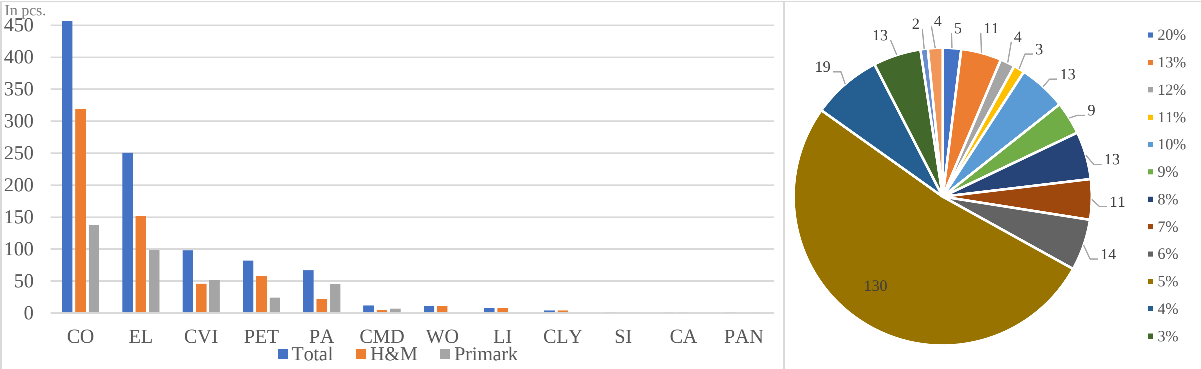


*Figure 4: Most popular fiber types and most used elastane content in blends for t-shirts in pcs*

For the haberdashery items and contaminants found on t-shirts, the most used with a total number of 119 are big prints. Furthermore, as seen in Figure 5, the group of patch/embroidery/small print is used a total of 26 times, making it the second most popular. Snap buttons and buttons are on place three and four with a total of 19 and 18 documented garments. Every garment has been dyed or bleached in some kind of way, some garments have different colored stripes knitted into the fabric to form a pattern. The figure also shows the numbers of mono-fiber garments without added haberdashery. For H&M, 198 out of 229 (86.4 %) mono-fiber garments are without haberdashery items, for Primark it is 63 out of 65 (96.9 %).

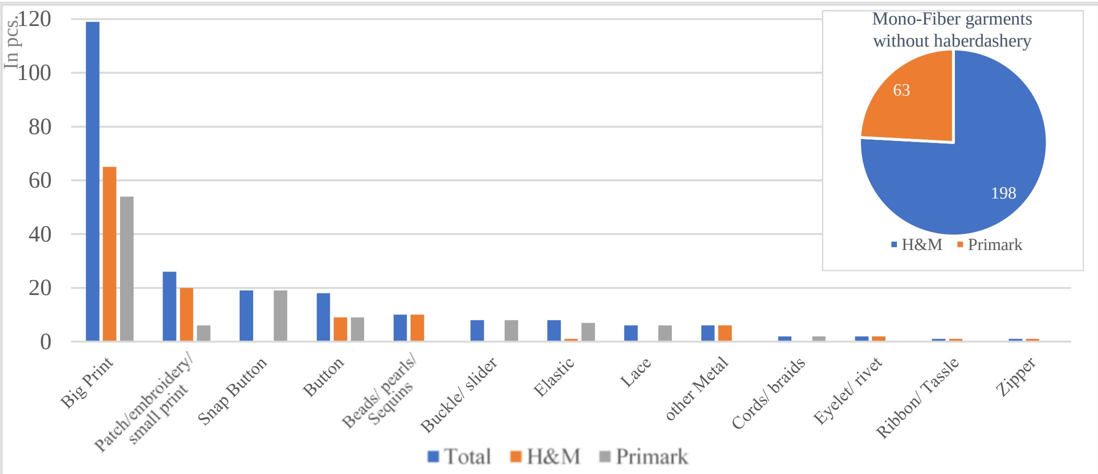


*Figure 5: Most utilized haberdashery items and contaminants for t-shirts by H&M and Primark in pcs and number of mono-fiber garments without added haberdashery*

## DISCUSSION

Within the analyzed garments, cotton did get utilized the most, with a total of 457 garments (73.9 %) containing cotton fibers. Polyester got utilized for a total of 82 garments (13.3 %), making it only fourth place after viscose and elastane. This may be due to a preference for cotton and cellulosic fibers of German consumers in summer. Elastane was present in a total of 251 (40.6 %) of garments. It is to be noted though, that elastane is only used in small quantities in blends, usually up to 5 %, for sportswear up to 20 %, to give more elasticity and comfort to a garment. This explains the high number of garments containing elastane fibers, though as seen in Figure 4, also showcases the importance of a better regulation of elastane content values in blends. As it is especially used for tighter fits, we would expect that men’s t-shirts may contain less styles with elastane. Though only used in small quantities, it is a highly relevant fiber for garments, thus poses to be a major contaminant and obstacle for recycling.
Viscose marks the third most used fiber, with 15.9 % of t-shirts containing viscose fibers in a blend. The other cellulose-based manmade fibers (MMF) add up to 2.7 % and are significantly less relevant.

The popularity of viscose fibers can be explained through the similarities of the fibers with cotton as well as their lower price and better availability compared to other cellulose-based MMFs. If the different MMs can be summarized for recycling is still rather unclear, more research regarding the suitability and compatibility is needed.

Less than half (47.6 %) of all analyzed t-shirts have been made from only one type of fiber, which is closely tied to the fit of the garments. Tighter garments often require some elastane content to ensure proper fit. It is remarkable, that a total of 77 different fiber blends with different fiber values have been used, of which only eight blends have been used by both brands. Of the 77 fiber blends, 24 blends were made up by three different types of fibers. Furthermore, the 53 2-fiber blends can be condensed to 16 blends with the same fibers present, disregarding their different values. This showcases the obstacle that unregulated blending of different fiber types poses for high quality F2F recycling and highlights the importance for ecodesign guidelines to include the regulation of blends regarding number and content value of fibers as well as compatibility.

T-shirts are often worn as a layering pieces or basics, and in those cases, usually do not contain any type of adornments. Statement pieces are usually adorned in some kind of way, most often with prints, beads or embroideries. Combinations of different types of adornments are common as well. As t-shirts usually do not require any type of closure, the usage of buttons or zippers is rather uncommon, aside as their use as design elements or for certain types of t-shirts like polo-shirts. This results in only 46 (7.4 %) documented closures, though it has to be mentioned, that especially the 19 documented cases of snap buttons are linked to bodysuits which require the closure in the crotch area. Most haberdashery items on t-shirts are easily localizable and mostly serve design purposes.

## CONCLUSION

Textiles itself are already a highly heterogenous waste stream, composed of a variety of different product groups each with their own specific requirements regarding fibers, closures, adornments and finishings. In this study, one product group for women has been examined, showcasing that there is already large variety within one group itself. It is already challenging to predict composition and contaminants for one product type, let alone for a whole mixed waste stream. For t-shirts specifically, ecodesign guidelines should focus on the composition of fiber blends, proposing several blends with preset content values to be used by all companies to reduce the heterogeneity of the waste stream. Especially elastane should be in the focus of action, as it poses to be a great contaminant in recycling. For haberdashery items and other contaminants, the compatibility with the main fibers and recycling technologies should be in focus. Design for easy disassembly at the end of life would further promote more heterogeneity of the waste.

The findings of this study help to better understand the composition of the product group t-shirts, making it a more attractive resource at their end-of-life for further processing by recycling companies, thus helping to enable F2F recycling and promoting a circular economy within the textile industry in the future. This study will get extended to cover more fashion brands and also different product groups in the future, to broaden the knowledge of the currently available garments on the market and how they will possibly influence recycling in a couple of years, when they will get collected as post-consumer waste. The expansion will also help to form a basis to formulate ecodesign guidelines for the other product groups.

## IMPLICATIONS

The authors declare that there are no conflicts of interests.

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# PROSPECT USE OF ADDITIVE MANUFACTURING FOR ORTHOPEDIC FOOTWEAR

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## ABSTRACT

Orthopedic footwear products show a high interest for people with various foot health problems. Their use offers support and stability for consumers' feet. The traditional way of producing orthopedic footwear products lack of accuracy buy not support various health problems of consumers feet. Advanced technologies, which are widely used in various industries, present an efficient method to produce customized orthopedic footwear. Starting from 3D foot scanning in various postures improves the fit and accuracy of these products. The digital information of the feet can also be used to analyze various foot problems and improve personalized footwear products. Their production through additive technologies as 3D printing presents a faster and more accurate way. Freedom to use various materials and 3D printing parameters helps to achieve the required physical and mechanical properties for orthopedic footwear products. Moreover, it supports the sustainable way of production through waste reduction. These case studies are shortly presented to give an overview of the disadvantages of traditional production and the advantages of the use of 3D technologies.

**Key words**: orthopedic footwear, additive technologies, customization, shoe lasts.

## INTRODUCTION

Orthopedic footwear is a product used to improve walking performance and foot stability. It belongs to the rehabilitation aids group and is included in the prosthetic and orthopedic products category.

Orthopedic shoes, even those named special shoes, are made individually for the patient and intended to prevent or correct foot or leg deformities during complex treatment. Anatomically, they ensure the correct position of the foot. Orthopedic shoes have a therapeutic or preventive effect on the human body during the entire period of wearing them, and therefore, the correctness of the shape and design of such shoes is extremely important (Werner M., & Wellmitz, G., 2001).

These special shoes have a wide target segment including children with congenital defects of the feet, children with impaired development or functioning of the feet, pregnant women, adults and children with injuries of the lower limbs, people with plegia of the lower limbs of various origins, people with diabetes, people with pathologies of the foot structure, patients after surgical interventions, patients with partial foot amputations, etc. Each case of developing orthopedic shoes is individual and requires considering all the factors that can affect the motor function of the foot.

In the practice of orthopedic production in Western European countries, orthopedic footwear is a separate important sector of footwear production, which has traditions, methods, and technologies that allow the production of decent, comfortable, high-quality, and aesthetic footwear (Seidich H., & Seidich, D., 2024).

Today, the situation in Ukraine presents new challenges to producers and scientists in various spheres of the national economy. With the beginning of a full-scale war, the need for prostheses increased dramatically due to the large number of amputations, especially of the lower limbs of the Ukrainian military. Moreover, a big part of the population suffers from orthopedic foot problems of various origins (flat feet, valgus deformity, heel spurs, hallux valgus, and others). Previously, the vast majority of patients were elderly. However, since the beginning of the war in Ukraine, the number of people with gunshot wounds of various types has increased significantly.

The manufacture of orthopedic insoles requires the use of a special technique for manufacturing the spatial shape of the orthosis based on the shape of the patient's foot, taking into account the peculiarities of foot biomechanics, recommendations of the orthopedic surgeon, and the peculiarities of the clinical and physiological condition of the foot (Forward Motion Medical, 2023). Such insoles are complex shapes made of materials with different physical and mechanical properties, connected into a single unit. The traditional way of manufacturing insoles involves laying out materials on a prepared plaster model or pad, thermoforming and gluing them, followed by processing on a grinding machine. Figure 1 depicts the orthopedic shoes that can be produced based on the adapted standard shoe last with overlays in certain areas (left side) and based on foot plaster cast (right side).

*Figure 1: The traditional ways to create the personalized shoe last.*

More details about the main steps followed to produce an orthopedic insole are depicted in Figure 2. The traditional technique for producing such insoles includes the steps of molding parts from EVA, gluing parts of different hardness, milling, and finishing the complex shape.

*Figure 2: Main steps to produce an orthopedic insole.*

However, the traditional method, which is still used nowadays, has some disadvantages, due to the low accuracy compared with the advanced technologies used nowadays as digital technologies. Data accuracy is one of the main requirements to be fulfilled to assure stability and comfort. It is worth mentioning here the number of different issues and difficulties encountered during the process of orthopedic shoe production as follows:

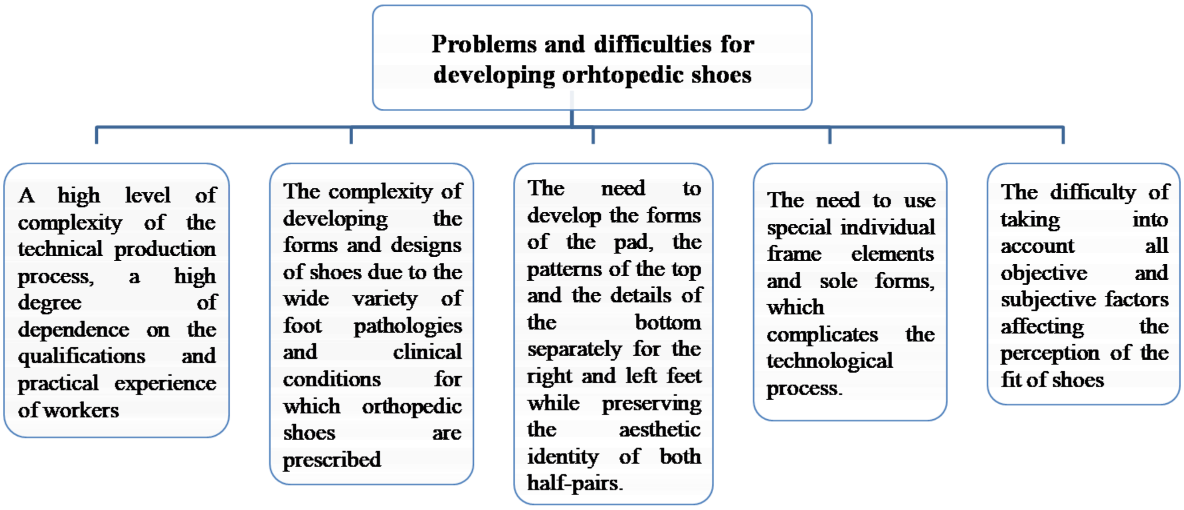


*Figure 3: Key issue in producing orthopedic footwear.*

## 3D TECHNOLOGIES AS NEW SOLUTONS FOR ORTHOPEDIC FOOTWEAR

The implementation of digital technologies in various industries has improved product manufacturing. Digital technologies not only increase the accuracy of design processes but also reduce time and avoid complex technological operations performed manually.

Unequivocal advantages can be seen in the use of 3D technologies for the development of inclusive products, orthopedic shoes, orthoses, and special products for people with disabilities; as such products require an exclusively individual approach and high accuracy of product parameters.

In a study done (Walker K.., et al.,2023) based on information about the foot's shape and relief, 4 pairs of individual orthopedic insoles were manufactured:  a pair of supportive and regular insoles made traditionally, and a pair of supportive and regular insoles made using 3D printing. Participants assessed forefoot and heel cushioning, arch support, overall insole condition, and overall shoe fit (size, width, etc.). The comparison of the results demonstrates the possibility of using 3D printing for the production of supporting and unloadin insoles because the participants of the experiment did not find a significant difference in the assessment of comfort. There are preliminary studies indicating that orthopedic insoles manufactured using additive production are effective in reducing pain sensations in the heel area (Xu R., & Wang Z., 2019 - Grat A., et al., 2018), and in altering the biomechanics of the lower limb (Mo S., et al., 2019).  At the current level of development of additive technologies and 3D printing materials, helps to achieve the needed physical and mechanical properties of footwear parts (Iacob M.C., et al., 2023).

The bottom of the shoe, consisting of the sole, orthopedic insole, and frame elements that fix the heel and heel part of the shoe, ensures the correct installation and biomechanics of the foot. The upper part of the shoe should wrap around the shape of the foot, without creating discomfort.

One of the main elements that ensure the correct shape of shoes is an orthopedic last. That can be modeled based on the 3D foot model generated by 3D scanning, or a plaster cast by the method of reverse engineering. 3D foot scanning is an important method to take the digital information of the feet that can be later used to analyze foot shape and its dimensions. The accuracy of digital data and their use at every moment without the need of the subject offer practical use of these data for shoe last or footwear personalization. Moreover, digital data on the feet can be used for analyzing the clinical condition of the feet of individual consumers or population groups (Kaptiurova D., et al., 2024 - Chertenko L., et al., 2023). Following are some of the 3D foot scanning uses:

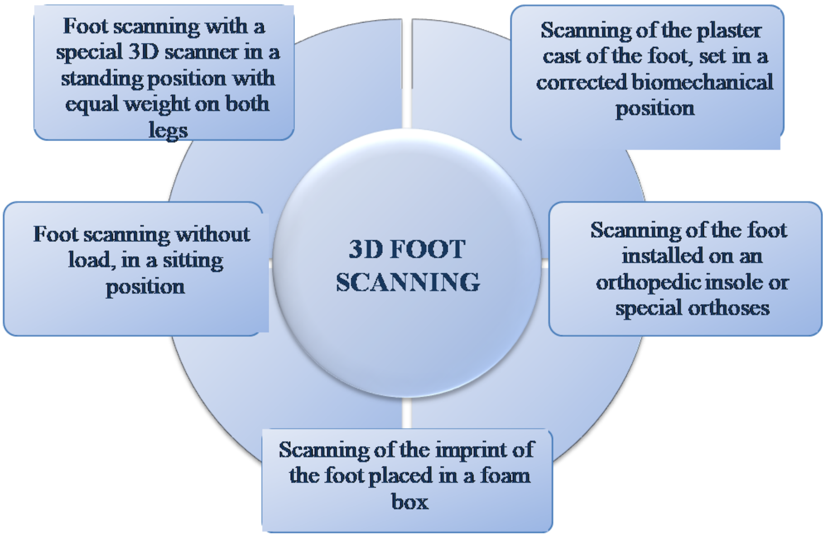


*Figure 4: Uses of 3D foot scanning for various purposes.*

The resulting file can be loaded into the environment of 3D CAD software for designing an individual shoe last. At the same time, in cases of simple deformations of the foot, we can modify the standard shoe last by adapting it to the parameters of the patient's foot according to the following parameters (Fig. 5).

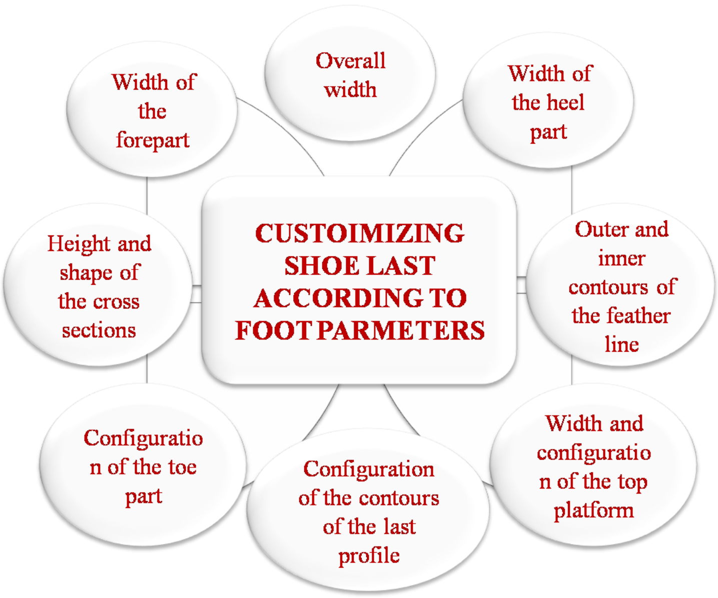


*Figure 5: the main operations of the shoe last modeling in the 3dCAD using reverse engineering.*

The bottom of the shoe, consisting of a sole and an orthopedic insole, performs a corrective or supporting function. For this, the shape of the bottom of the shoe can have one or more of the following shape elements, depending on the necessary adjustments (Fig. 6).

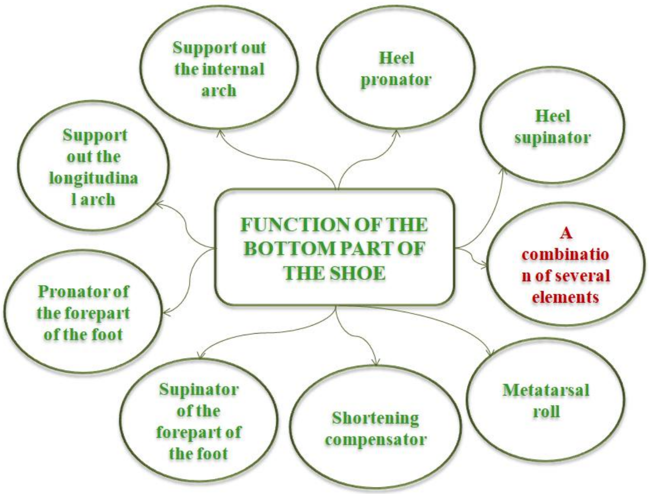


*Figure 6: Functions of different types bottom part of the orthopedic footwear.*

The basis is a digital model of a standard orthopedic insole with all standard elements. A scanned image of the baropodometry, and a 3D scan of the foot are imported into the modeling environment. Next, all these elements are combined, and aligned according to the dimensional zones. After importing a 3D scan of the plantar surface of the foot into the workspace we edit the shape of the orthotic insole according to the foot's bottom shape.

The inner filling of the insole must be different in separate areas depending on needed requirements. The unloading insert elements are modeled in the insole body in the areas of high pressure (in the heel area and ball area) and have distinctive filling parameters.

After modeling the shape of the shoe last and orthopedic insole, the designed shapes are saved in STL format and further processed in slicer software for preparation for 3D printing. The general algorithm of the improved process of developing and manufacturing orthopedic shoes looks like this:

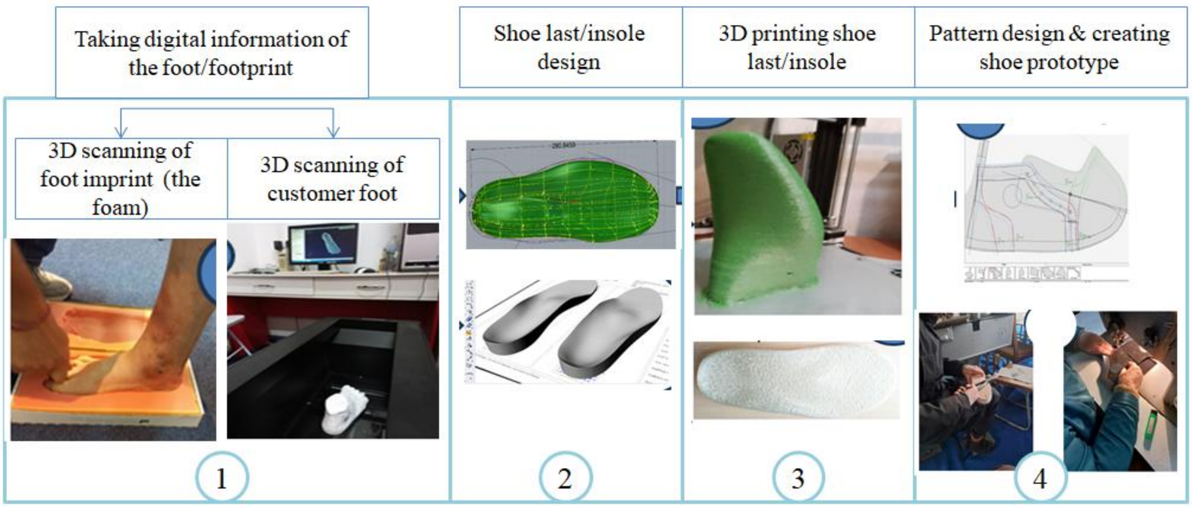


*Figure 8: The main stages of process of creating the personal orthopedic footwear.*

**CONCLUSION**

An effective solution to the production of orthopedic shoes can be found in the wide application of advanced digital technologies. The possibility of developing products in online mode presents a great advantage. Advanced technologies, such as 3D foot scanning are important methods for creating virtual copies of consumers' feet used for shoe modeling. Moreover, the digital information of the foot can be used to study the clinical condition of the feet of various consumers or population groups. Additive technologies, such as 3D printing help to produce personalized footwear parts as shoe lasts, insoles, and orthoses, which are modeled based on individual feet models. The freedom of using different materials and 3D printing parameters depicts an efficient way to achieve the required physical and mechanical properties of footwear parts, highly required for the production of prosthetic and orthopedic products.

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# SUSTAINABLE DYEING OF CATIONIZED COTTON WITH SPIRULINA ALGAE

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**ABSTRACT**

Phycocyanin, a natural blue pigment derived from the algae Spirulina, is increasingly recognized for its role as a safe and environmentally friendly dye alternative in various industries, particularly food and textiles. This colorant exhibit low affinity for textile fibers, especially cotton, making it challenging to achieve effective dyeing using conventional methods. In this study, phycocyanin extracted from Spirulina was employed as a sustainable natural colorant for dyeing of cotton fabric. To improve the dyeability of cotton, a cationizing agent was employed to impart cationic moieties on the cellulosic chains. The optimal concentration of the cationizing agent for achieving the maximum dye exhaustion was obtained and the effect of dyebath pH and temperature on the color strength of the dyed cationized cotton was investigated. The results showed that the maximum color strength is obtained when 8%owf of Croscolor DRT is used for cationization of cotton and the optimal pH and temperature of the dyebath were 5 and 60°C, respectively. The samples dyed under optimal condition showed moderate wash fastness and weak light fastness. This study confirms the applicability of phycocyanin from Spirulina in cotton dyeing, but highlights the need for improvements in fastness properties.

**Key words**: Spirulina, Sustainability, Cationization, Cotton, Natural Dyeing

## INTRODUCTION

The textile industry is undergoing a significant transformation as the demand for sustainable practices rises. While synthetic dyes have several advantages, they pose severe environmental concerns due to their reliance on petrochemical sources and the toxic byproducts generated during their production and application. In contrast, natural dyes sourced from renewable materials offer a promising alternative that aligns with eco-friendly initiatives. The shift towards sustainable dyes not only reduces carbon footprints but also minimizes water pollution and the depletion of natural resources. This transition is particularly vital in the context of cotton dyeing, where the environmental impact can be substantial (Repon, Islam et al. 2023, Repon, Islam et al. 2024).

Among the various sources of natural dyes, algae have emerged as a noteworthy option due to their rapid growth, high pigment content, and minimal resource requirements. Phycocyanin, a blue pigment derived from spirulina algae, has garnered attention for its vibrant color and potential health benefits. As a phycobiliprotein, phycocyanin not only serves as a natural dye but also possesses antioxidant properties, making it an attractive choice for both aesthetic and functional applications in textiles. Its ability to impart color without harmful chemicals positions it favorably within the sustainable dyeing paradigm (Fernandes, Campos et al. 2023, Salman, Adeel et al. 2024).

Recent studies have explored the applications of algae in textile dyeing, particularly focusing on cotton. The LIFE SEACOLORS project successfully demonstrated the feasibility of extracting dyes from various algal species, including spirulina, and applying them to cotton fabrics. This project validated that these natural dyes could effectively replace synthetic alternatives while offering a wide range of colors and shades (LIFESEACOLORS 2014). Moldovan et al. extracted four different algae species containing dyes with Phycocyanin, Phycoerythrin, Carotenoid, and Chlorophyll structures and applied them on cotton and wool in presence of different metal and bio mordants using exhaust dyeing and printing techniques. They obtained good results and mentioned the light fastness as the main limitation of the use of algal dyes (Ferrándiz, Moldovan et al. 2016, Moldovan, Ferrandiz and Bonet 2017, Moldovan, Ferrandiz et al. 2017, Moldovan, Franco et al. 2021, Moldovan 2022, Moldovan, Bou-Belda et al. 2022). Additionally, research by Ciptandi et al. detailed an experimental approach using spirulina powder mixed with aluminum sulfate to dye cotton fabric, achieving satisfactory results in terms of color retention and application methods (Ciptandi, Susilowati and Ramadhan 2021).

A recent study by Wu et al. highlighted a novel method for enhancing the durability of phycocyanin on silk fabrics through cross-linking with genipin, a bio-based crosslinker. This approach not only improved the colorfastness of the dye but also endowed the fabric with antioxidant and UV protective properties, showcasing the multifunctional potential of phycocyanin in textile applications (Wu, Zhou and Tang 2023). Moreover, a study investigating phycocyanin's potential as a hair dye indicated that it retains color well even after multiple washes, suggesting its stability and effectiveness as a dyeing agent (Kraseasintra, Tragoolpua et al. 2022). This reinforces the notion that phycocyanin can be successfully utilized beyond just food and cosmetic applications, expanding its utility into textiles.

The integration of phycocyanin and other algal-derived dyes into cotton textiles not only represents a step towards reducing environmental impact but also opens up new possibilities for innovation in the textile industry. Continued research and development in this area are essential for optimizing dye extraction processes and enhancing colorfastness, ultimately contributing to a more sustainable future for textile production (Mutaf-Kılıç, Demir et al. 2023).

In this study, the phycocyanin obtained from Spirulina was used for the dyeing of cotton fabric. To enhance the affinity of cotton fibers, cationization was done before the dyeing. The effects of the process parameters as well as the fastness properties of the dyed samples were investigated.

## EXPERIMENTAL

### Materials

Bleached cotton fabric (110 gm-1) was purchased from Mazandaran Textile Co., Iran. Phycocyanin powder was purchased from BioGreens, Isfahan, Iran. Cationizing agent (CROSCOLOR DRT) was obtained from Eurodye-CTC, Belgium.

### Methods

***Cationization:*** Different concentrations of the cationizing agent (1-16%owf) was applied on cotton fabrics by exhaustion method at 50°C for 30 min (L:G=50:1).

***Dyeing:*** cationized cotton fabrics were dye with 1%owf of the phycocyanin at different temperatures (40-80°C) and pH values (5, 7, and 9), while keeping the liquor ratio at 50:1.

***Color measurement:*** The reflectance of the dyed fabrics was measured using Color eye 7000A (X-rite, USA) in the range 360-750 nm nder illuminant D65 and 10° of standard observer. Color strength was calculated according to the Kubelka–Munk equation. The UV-Vis spectrum of phycocyanin solution was measured on a UV-Vis spectrophotometer (EU-2200, Onlab, China) in the range of 300-700 nm.

***Fastness properties:*** The fastness of the fabrics dyed under optimal condition against light and washing were measured according to ISO 105-B02 (2014) and ISO 105-C01 (2006), respectively.

## RESULTS AND DISCUSSIONS

Figure 1 shows the UV-Vis spectrum of the phycocyanin solution (1%) which shows the peak at 615 nm as the characteristic peak ($\lambda_{max}$) which is in accordance with the previous studies (El-Naggar, Hussein and El-Sawah 2017, Moldovan 2022).

As shown in figures 2 and 3, the color strength was increased by increasing the cationizing agent (DRT) concentration from 1%owf up to 8%owf, while further increase to 16%owf did not make a significant improvement in the color strength. So, 8%owf was selected as the optimal concentration of DRT for the next steps of the study. It seems that by using 8%owf of DRT, maximum possible reactions between the cationizing agent and cotton fibers have taken place and no more cationic sites are added to cotton fibers by further increasing the DRT concentration in the modification bath. As shown in figure 4, color strength was reduced by increasing the dyebath pH from 5 to 9. Phycocyanin structure consists of a monomer formed by two helix-shaped subunits, called alpha (α) and beta (β), with one bilin chromophore attached to the α subunit and two of them to the β subunit. The chromophore, called phycocyanobilin (figure 5), is responsible for the blue color of the molecule and it consists of an open chain tetrapyrrole group that binds proteins through a thioether bond (Pez Jaeschke, Rocha Teixeira et al. 2021). As the chromophore carries negative charge, increasing the cationic charge of cotton increased the adsorption of the Phycocyanin onto the modified cotton fibers due to ionic attractions.

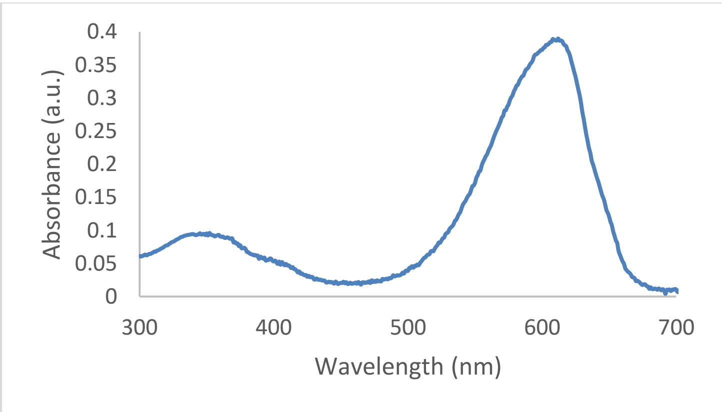


*Figure 1: UV-Vis spectrum of phycocyanin in water*

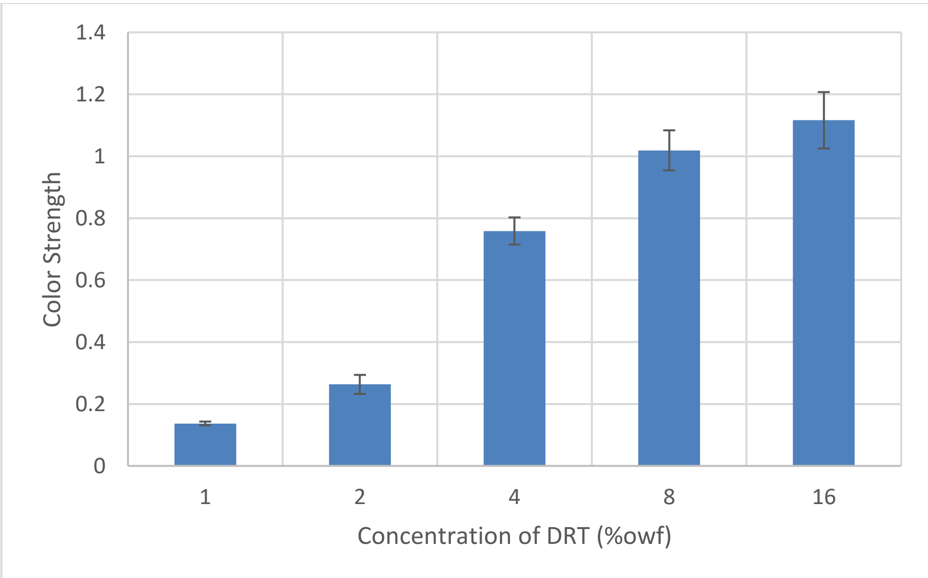


*Figure 2: Effect of cationizing agent concentration on color strength of the dyed samples (620 nm)*

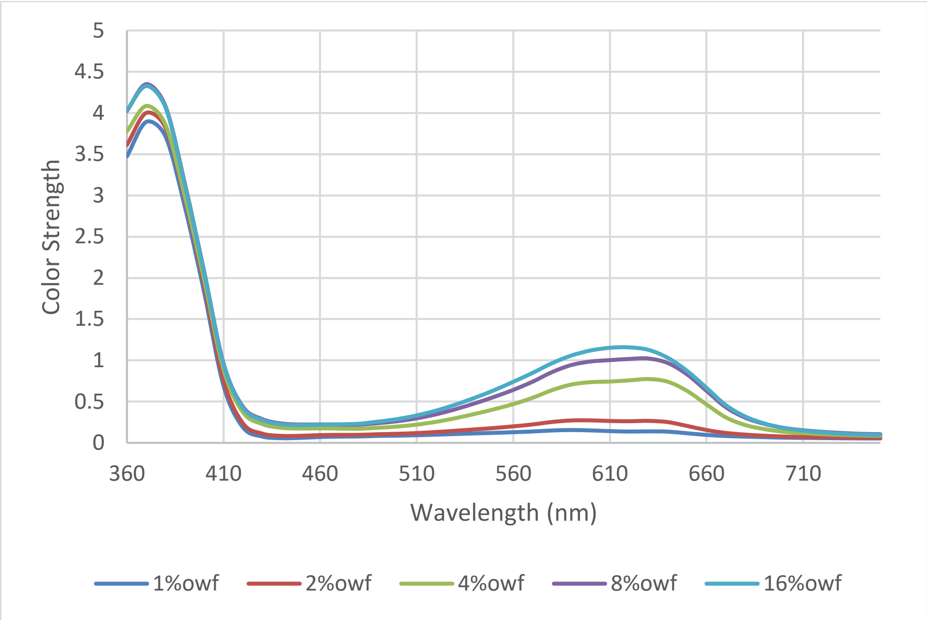


*Figure 3: Effect of cationizing agent concentration on color strength of the dyed samples (full range)*

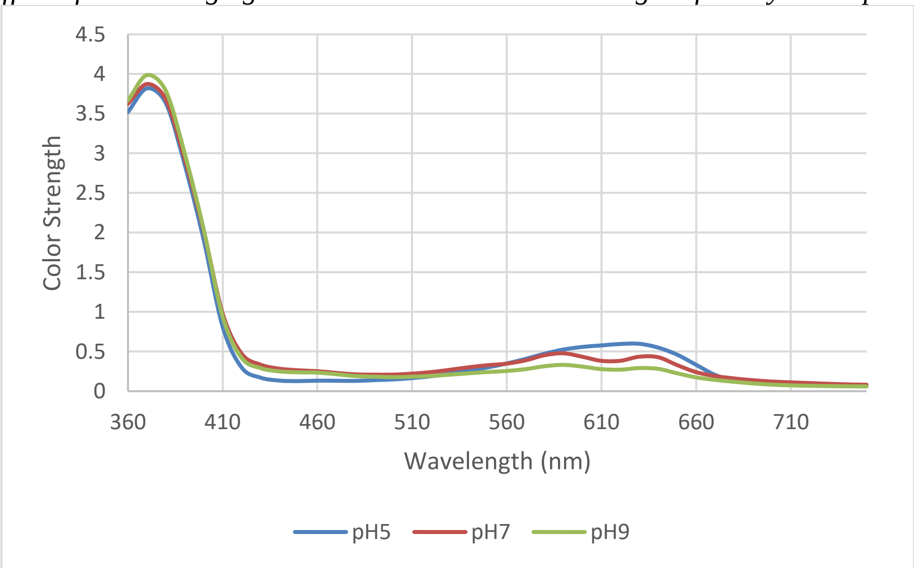


*Figure 4: Effect of dyebath pH on color strength of the dyed samples (full range)*

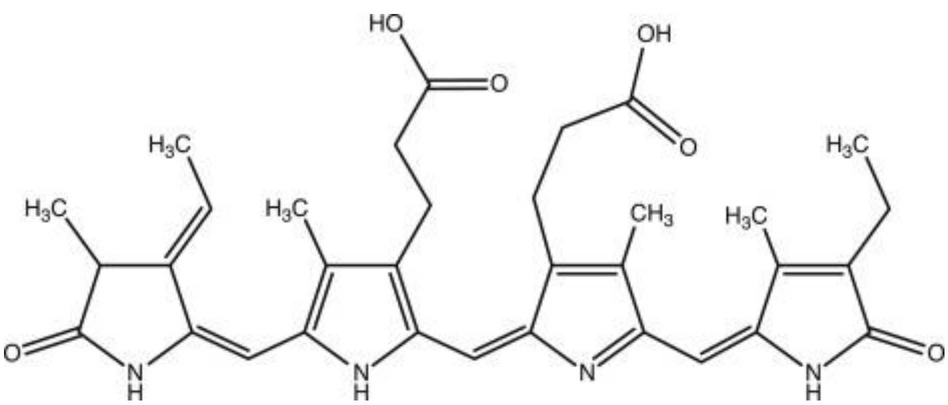

*Figure 5: Chemical structure of phycocyanobilin (Zeece 2020)*

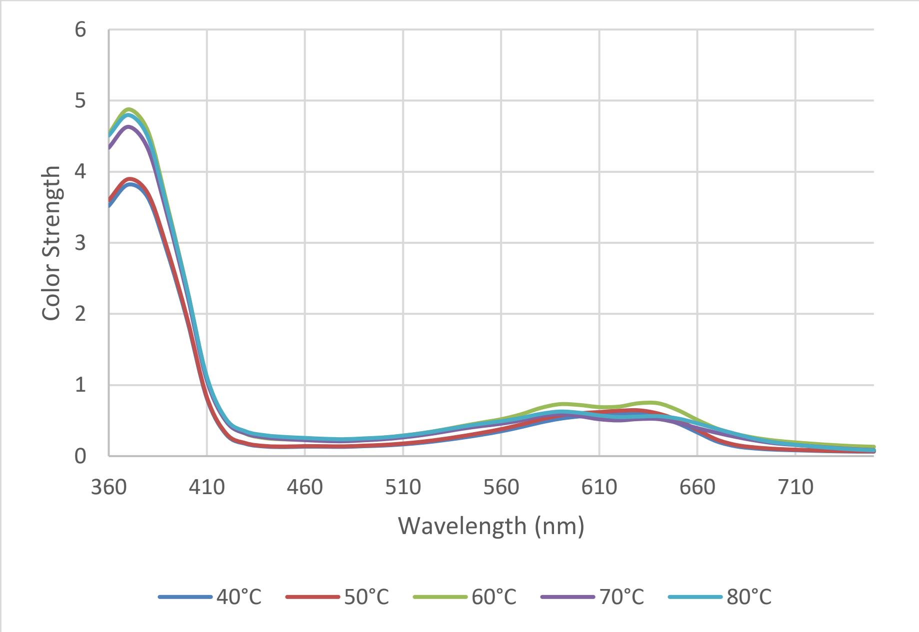


*Figure 6: Effect of dyebath temperature on color strength of the dyed samples (full range)*

Figure 6 shows that the maximum color strength was obtained when the dyeing was done at 60 °C and the color strength was reduced by further increasing the dyebath temperature. This confirms the instability of the phycocyanin at elevated temperatures (Chaiklahan, Chirasuwan and Bunnag 2012).

Table 1 shows the fastness properties of the sample dyed under optimal condition against washing and light. It can be seen that the wash fastness is moderate, while the fastness against artificial light is weak. further studies to improve the fastness properties of this dye on cotton is necessary.

*Table 1: Fastness properties of the sample dyed under optimal condition*

| Fastness Rating | Wash fastness | | | Light fastness |
|---|---|---|---|---|
| | Color change | Staining on cotton | Staining on PET | |
| | 3 | 4 | 5 | 2 |

**CONCLUSION**

The results of this study showed that cationization of cotton improved its dyeability wit the phycocyanin extracted from Spirulina. The optimum concentration of the cationizing agent (Croscolor DRT) was 8%owf. The optimal pH and temperature of the dyebath were 5 and 60 °C, respectiveley. The fastness against washing was moderate and the light fastness was weak.

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# CMYK INK SOLID-TONE SUBLIMATION PRINT QUALITY

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**ABSTRACT**

The polyester fabric was printed using sublimation printing in cyan, magenta, yellow, and black solid-tone color with a 100 % total ink limiting level. The color strength and print mottle were monitored on the printed fabric. Print mottle was estimated by the grey level co-occurrence matrix (GLCM) image processing method, while color strength was determined by reflectance spectrophotometry. The black print had the lowest entropy, contrast, and correlation and the highest energy and homogeneity. The black print possessed the most uniform ink surface with the highest color strength. Solid-tone of magenta and yellow print showed similar solid-tone uniformity. Namely, slightly better solid-tone reproduction possessed yellow print. Cyan ink solid-tone print showed the worst results for the GLCM parameters and color strength, which made this print the worst in terms of solid-tone surface uniformity reproduction and color strength. Choosing a suitable color design for the sublimation printing helps to achieve different color designs, and reach the required print quality and customer desire.

**Key words**: sublimation printing, CMYK ink, solid-tone, print mottle, GLCM analysis

## INTRODUCTION

Digital printing is a great substitute for traditional print. Over the last few years, the graphic printing and textile printing industries have adopted digital printing methods. The primary reasons behind the progression to digital printing are the opportunities for professionalized printing, cost-efficiency, and flexibility of the machines. The textile printing industry is placing their traditional screen-printing technique with digital printing methods too. Sublimation printing is an ideal digital alternative that offers multiple color printing, photographic imagery, and personalized printing possibilities [1]. Also known as “dye-sub” and “dye sublimation print”, sublimation printing is a flexible digital printing method that helps textile designers with creativity and production output. The sublimation printing process is carried out by transferring the sublimation dyes to a medium that has a specially designed inkjet printer. After transferring the dye to the medium, they are then transferred to a heated object and pressurized through a commercial heat press [2]. In sublimation printing the CMYK color model is commonly used [3,4]. The basic primaries in sublimation printing are cyan, magenta, yellow, and black. Yellow is usually added to control the hue and lightness of the produced colors. Black ink is added to increase the contrast and details in dark shades and reduce general ink consumption.

Consumers desire to be in flow with fashion trends by wearing textile products with different colors. In addition to the durability of the textile products [5-7], they also pay great attention to the intensity of the color print. However, the challenge for technologists and industry is to overcome the solid-tone ink surface ink uniformity (print mottle). It is crucial to know the uniformity of the print that can be obtained from CMYK primary inks, as this can significantly change the unevenness, especially in multi-color print. Therefore, designers, industry, and scientists need to know what uniformity basic CMYK inks provide in order to achieve a broad range of prints in different colors with high uniformity.

This research aimed to investigate the change in quality by CMYK color system ink settings when sublimation printing on fabric in cyan, magenta, yellow, and black solid-tone patches with the 100 % ink limiting level.

## EXPERIMENTAL PART

### Material

White fabric, 97 % polyester, and 3 % elastane, with 160 g/m$^2$ weight, 0.36 mm thickness, and 43 cm$^{-1}$ and 22 cm$^{-1}$ warp and weft densities, respectively, with twill structure, was used.

### Printing Procedure

The test image for printing was created in Adobe Illustrator software in the CMYK color system and consisted of the rectangle (3.5cmx3.5cm dimensions) in CMYK solid-tone color patches with 100 % total ink limiting level. The patches were 100% (C=100%,M=0%,Y=0%,K=0%) cyan, 100% (C=0%,M=100%,Y=0%,K=0%) magenta, 100% (C=0%,M=0%,Y=100%,K=0%) yellow, 100% (C=0%,M=0%,Y=0%,K=100%) black. The test image was printed on commercially available sublimation transfer paper with 105 g/m$^2$ weight by an A4 format EPSON ink jet printer with four CMYK ink jet channels. The printer was installed with sublimation ink SUBLYFUN by Print Equipment Gmbh&Co. Pre-pressing, and sublimation printing processes were performed by the press model BESTSUB SB3A (38cmx38cm) and medium pressure (2.3-3.5 bar). The pre-pressing of the fabric was conducted at printing temperature for 6 s, and then sublimation printing was performed at 190 °C temperature and a pressing time of 120 s. Afterward, the printed fabric was cooled to room temperature, and the baking paper was removed. The sublimation printed fabric was conditioned and tested in a standard atmosphere (temperature 20 °C and 65 % relative humidity) for 24 hours.

### Methods

#### *Color Strength*

The color strength (K/S) of printed fabric was determined by measuring the corresponding reflectance value using the X-Rate Color i7 reflectance spectrophotometer and calculating the K/S value using the Kubelka-Munk equation:

$$K/S = \frac{(1 - R_{\lambda max})^2}{(2R_{\lambda max})}$$

Where: K is the absorption coefficient, S is the scattering coefficient, and R is the reflectance value of the print at the wavelength at maximum absorption.

#### *GLCM (Grey level co-occurrence matrix) image processing method*

Print mottle was assessed by the image analysis method using a grey level co-occurrence matrix (GLCM) [8]. After sublimation printing, printed fabrics were digitalized by flatbed scanner EPSON L3151 at 600 dpi scanning resolution without auto-correction. The actual rotation angle determined by the orientation of the sample set in the sample input was 90º. Scanned images in the TIFF files were scaled at 500x500 pixels for easier processing in MATLAB. Then, samples were subjected to GLCM analysis to obtain quantitative print uniformity results. GLCM analysis was done in MATLAB software with code according to Uppuluri [9] using the following parameters: the number of grey levels was set to 8 ($L^*$ channel), the distance between two pixels (d) was set to 1, and four angles of orientation were used (horizontal 0°, right-diagonal 45°, vertical 90°, and left-diagonal 135°). Print mottle using MATLAB code was assessed through contrast, homogeneity, energy, entropy, and correlation parameters. The results presented for each individual GLCM parameter are the mean value of 3 measurements at a confidence level of 95%.

**RESULTS AND DISCUSSION**

Temperature and pressing time sublimation printing parameters had an influence on the color strength of black color print [2]. The highest color strength was reached at 190 ºC printing temperature and 120 s pressing time. This printing temperature and pressing time were used in this research to analyze color strength and print mottle of cyan, yellow, and magenta, and compare with black print. Sublimation prints are commonly printed in full color or multicolor print. For that reason, it is necessary to have data on the basic colors of the sublimation printing. All colors in sublimation printing are obtained by mixing cyan, magenta, yellow, and black [10-12]. In Figure 1 is shown color strength of the print in cyan, magenta, yellow, and black color. Black had the highest K/S value, followed by yellow, magenta, and cyan ink. Cyan ink had the lowest K/S values. It can be noted that its K/S was significantly lower than the K/S values for black, yellow, and magenta prints. The black and yellow prints had similar values.

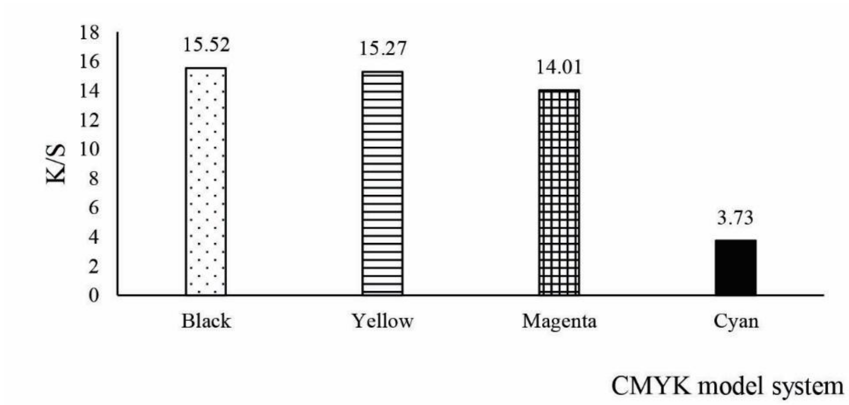


*Figure 1: K/S values of prints*

In Figure 2 are presented obtained print mottle parameters for cyan ink solid-tone patches. It can be noticed that all samples have low values of energy and contrast, correlation values are in the middle range, while entropy and homogeneity have high values. It can be noticed that the GLCM parameter entropy had the highest value for all colors (Figures 2-5), which can be explained by the strong, easily perceptible texture pattern on the fabric. GLCM parameters for magenta ink solid-tone patches are shown in Figure 3. It can be noticed that print in magenta color possessed uniform solid-tone ink surface; little higher quality had print magenta print compared to cyan color print.

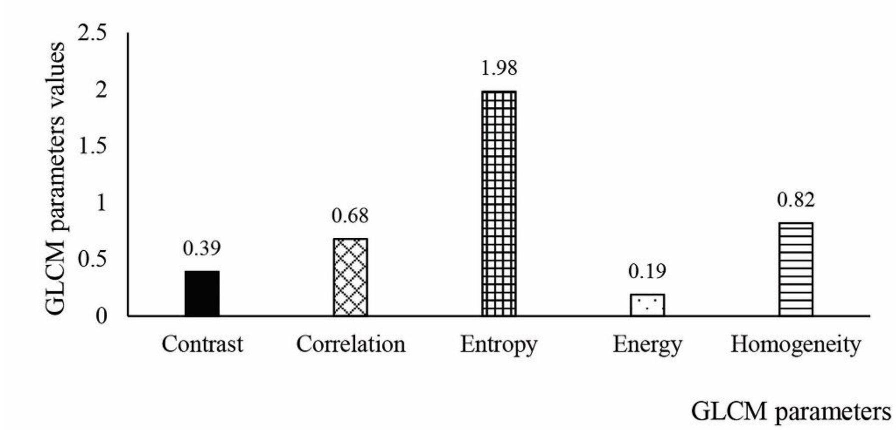


*Figure 2: GLCM parameters of cyan sold-tone print*

Namely, slightly better solid-tone reproduction possesses magenta print, which showed better behavior for five out of five parameters: contrast, correlation, entropy, energy, and homogeneity. As in the case of magenta solid-tone patches, yellow prints also showed uniform solid-tone reproduction quality. The print mottle of yellow print is shown in Figure 4. Solid-tone patches in magenta and yellow color showed similar solid-tone surface uniformity results according to GLCM parameter analysis. It can be seen that slightly better solid-tone reproduction possesses print made in yellow color, which showed better behavior for two out of five parameters: entropy and homogeneity.

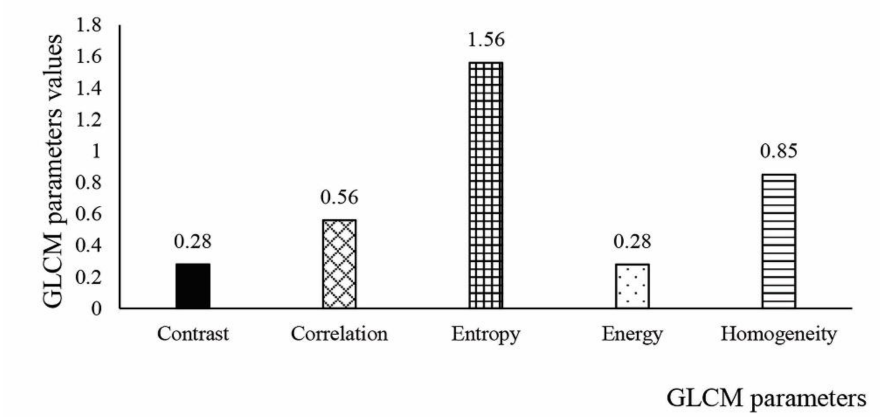


*Figure 3: GLCM parameters of magenta solid-tone patch*

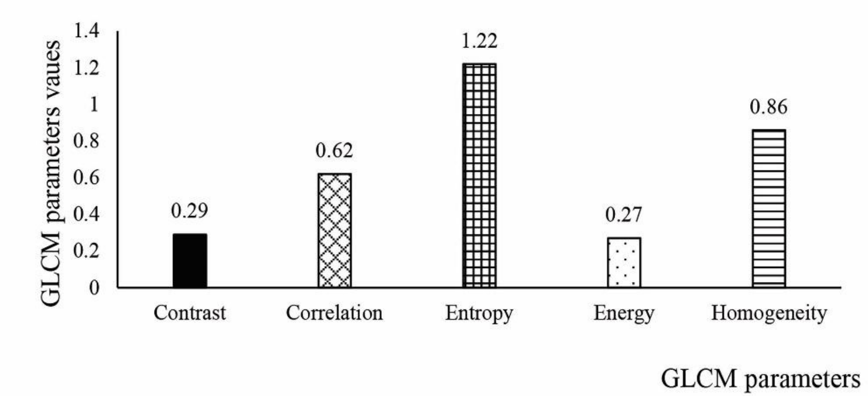


*Figure 4: GLCM parameters of yellow solid-tone patch*

In Figure 5 are presented obtained print mottle parameters for black ink solid-tone patches. A different trend was recorded compared to previously conducted ink solid-tone patches. Print made with black ink showed the best results for all considered parameters, which made this solid-tone patch print reproduction the best.

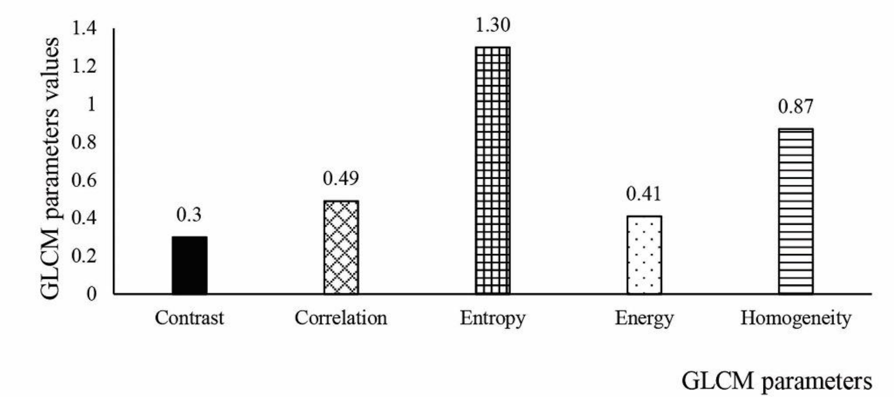


*Figure 5: GLCM parameters of black solid-tone patch*

## CONCLUSION

The effect of change in color strength and print mottle was analyzed to determine print quality obtained by sublimation printing at four ink colors on fabric in cyan, magenta, yellow, and black solid-tone color with 100 % total ink limiting level. The results indicated that low values for the contrast parameter and high values for the entropy and homogeneity parameters were characteristics of the obtained samples, while medium values were characteristics of the energy and correlation parameters. Comparing obtained prints with each of the four colors, certain differences can be obtained for values of all five GLCM parameters, indicating that the print obtained in black color had a uniform surface and that print in cyan color had a large non-uniformity (high print mottle). Print in black color had the lowest entropy, contrast, and correlation and the largest energy. Choosing the right color design for sublimation printing makes it possible to achieve different color designs, reach the required print quality, and balance price, quality, and customer desire.

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# RESEARCH ON SEAM PERFORMANCE PROPERTIES OF TRADITIONAL AND RECYCLED SINGLE JERSEY FABRICS

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## ABSTRACT

This research aims to determine the optimal sewing conditions for achieving high-quality seam performance in knitted apparel, with a focus on recycled polyester fibers widely used in the industry. The study examines four types of single jersey knitted fabrics: two conventional polyester elastane fabrics (crepe and sandy) and their recycled counterparts. All fabrics are commonly used in garment manufacturing. The recycled polyester fabrics are produced from plastic bottles and textile waste, contributing to sustainability efforts in the textile industry. Within the scope of this study, sewing performances were compared between knitted single jersey fabrics produced from conventional polyester fibers and those with recycled content in different proportions. Seam tensile strength was examined using various sewing parameters, including stitch direction, stitch type, stitch density, and sewing thread type.

The research analyzed the primary physical properties of the selected fabrics, including weight, knitting structure, thickness, and strength. Subsequently, test specimens were sewn, and their seam tensile properties were evaluated. The study encompassed 96 variation samples using four fabric types, three sewing types, two sewing directions, two sewing densities, and two sewing thread types. A total of 298 samples were tested, with each variation reproduced in triplicate for three repeated tests. The data obtained from these experimental studies were statistically analyzed to assess the performance of recycled polyester fabrics compared to their conventional counterparts. This study contributes to the growing body of knowledge on sustainable textile production, offering insights into the viability of recycled polyester fibers in high-performance knitted apparel manufacturing.

**Keywords**: Seam quality, seam strength, seam performance, recycled polyester, RPET, textile sustainability, knitted fabric, elastane, tensile strength

## INTRODUCTION

### Recycling in the Textile and Apparel Industry: A Sustainable Approach

In recent years, environmental sustainability has become a key managerial issue, and both researchers and practitioners are devoting increased attention to the topic as they face the challenge of achieving a balance between environmental and business needs (Caniato, et al., 2012). The textile and apparel industry is significantly transforming in response to global environmental challenges. This shift is primarily driven by the European Union's Green Deal, an ambitious program launched in 2019 to make Europe climate-neutral by 2050. The Green Deal affects EU countries and has far-reaching implications for nations with strong trade relations with the EU, such as Turkey.

One of the most promising developments in this area is the use of recycled polyester, or rPET (recycled polyethylene terephthalate). rPET is gaining attention as an environmentally friendly material that contributes to sustainability efforts. It is primarily produced from plastic bottles, fishing nets, and textile waste, effectively reducing dependence on fossil fuels and lowering carbon dioxide emissions (McCullough and Sun, 2019).

The textile industry's shift towards recycled materials like rPET is not just an environmental necessity but also a response to changing consumer preferences and regulatory pressures. As the world moves towards a more circular economy, the adoption of recycled polyester and similar materials is likely to increase, driving innovation and sustainability in the textile and apparel sector.

### Sewing Performance Characteristics in Ready-to-Wear Clothing

The ready-to-wear clothing industry faces a crucial challenge: producing high-quality garments quickly and cost-effectively while adapting to sustainable practices. Sewing performance, particularly with recycled materials, has become a key focus in this evolving landscape.

Sewing-related errors often lead to product downgrades, causing significant financial losses. While research exists on optimal sewing parameters for traditional fabrics, there's a notable gap regarding recycled fiber fabrics, especially in knitted fabrics containing elastane (Yıldız and Pamuk, 2021).

To address this, a study compared knitted fabrics made from rPET fibers with those from classic PES fibers. The research examined breaking strength, elongation, air permeability, and moisture management. Uniquely, it investigated sewing performance under various parameters, comparing recycled fabrics directly with classic polyester fabrics.

The study also analyzed seam-breaking strength, crucial factors in assessing garment durability and quality. This comprehensive approach provides valuable insights into the challenges and opportunities presented by recycled materials in the sewing process.

## MATERIAL AND METHOD

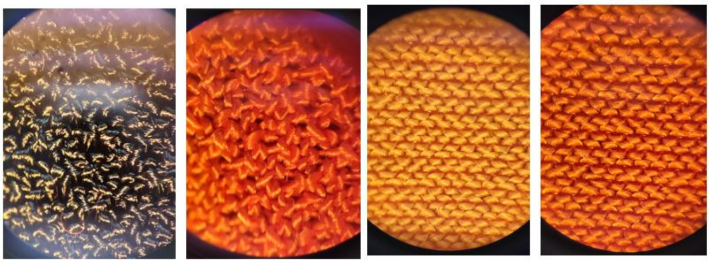
### Material

This research section explores materials used in textile production, focusing on knitted fabrics commonly employed in garment manufacturing. The research examines four fabric types, including both conventional and recycled versions of single jersey constructions. The technical specifications of the fabrics used in the study are shown in Table 1.

*Table 1: Fabric properties used in the study*

| Fabric Code | Knit Tpe | Material Type | Composition |
|---|---|---|---|
| Fabric 1 | Jersey (crepe) | Conventional | 95% Polyester 5% EA |
| Fabric 2 | Jersey (crepe) | Recycled | 60% Polyester 35% Recycle Polyester 5% EA |
| Fabric 3 | Jersey (sandy) | Conventional | 95% Polyester 5% EA |
| Fabric 4 | Jersey (sandy) | Recycled | 60% Polyester 35% Recycle Polyester 5% EA |

To ensure clarity in the research, each fabric was dyed a different color. Microscopic analysis confirmed the structural similarity between conventional and recycled versions of each fabric type (see also Figure 1). The study also investigated the impact of sewing materials on garment quality, utilizing two types of 24-tex sewing threads, which are shown in Table 2, a standard in the industry. To control variables, the study employed a consistent needle type across all experiments - an Organ brand, Nm 65, size 9 sewing needle. This methodical approach to material selection and processing demonstrates the researchers' commitment to producing reliable, industry-relevant results in the field of textile and garment production.



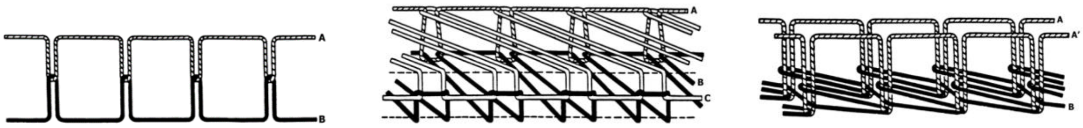
(a) (b) (c) (d)

*Figure 1. Microscopic images of the fabrics used in the study: (a) K1 coded classic method crepe single jersey fabric, (b) K2 coded recycled crepe single jersey fabric, (c) K3 coded classic method sandy single jersey fabric, (d) K4 coded recycled sandy single jersey fabric.*

*Table 2: Sewing thread properties used in the study*

| Sewing Thread Code | Description | TEX | Ticket |
|---|---|---|---|
| D1 | Staple polyester | 24 | 120 |
| D2 | Polyester corespun with polyester wrap | 24 | 120 |

Also, to ensure clarity in the research, the three types of stitches used in the samples prepared by sewing during the study are shown in Figure 2.



*(a) (b) (c) Figure 2. Three sewing types used in the study:*
*(a) Lockstitch 301, (b) Three thread overedge 504, (c) Chainstitch 406 (ASTM D 6193)*

**Measurement and Analysis**

The study began with proper sample conditioning, ensuring all materials were exposed to consistent atmospheric conditions (20 ± 2ºC temperature, 65 ± 4% relative humidity) for at least 24 hours prior to the experimental study. Researchers then conducted a series of tests to measure critical fabric characteristics, including weight, thickness, breaking strength, and elongation. Each test utilized specialized equipment and adhered to specific industry standards.

Notable procedures included using precision scales for weight measurement, digital gauges for thickness, and universal testing machines for strength assessments.

Throughout the testing process, researchers emphasized accuracy by taking multiple measurements for each parameter. This methodical approach provides a robust framework for comparing the performance and physical properties of recycled polyester fabrics against their conventional counterparts, contributing valuable data to the field of sustainable textile production.

***Weight Properties***

A VAHA DIG. LABOR. WP60-C brand precision scale was used for fabric weight measurement. After conditioning, the test fabric samples were cut from different areas using a circular template with an area of 100 cm² (three samples per fabric) with the help of a sample cutting device. These samples were then weighed on the precision scale. After calculating the average weight, the fabric weight was determined in gr/m².

***Thickness Properties***

Thickness measurement was performed using the Digital Thickness Gauge M034A model fabric thickness testing device from SDL Atlas company. Fabric thicknesses were determined according to the TS 7128 EN ISO 5084 standard. The measurements were carried out with 20 cm² fabric samples under a pressure of 200 g, with 3 repetitions.

***Fabric Tensile Properties***

The breaking strength and elongation at break values of the fabrics were measured using a Zwick Roell ZO10 universal yarn and fabric strength testing machine, according to the method defined in the TS EN ISO 13934-1 standard, with 5 repetitions. During the test, the distance between the clamps in the device was set to 100 mm, and the clamp speed was adjusted to 100 mm/min. Five samples each, measuring 20 cm x 6 cm, were prepared from the conditioned fabric in both warp and weft directions.

***Seam Tensile Properties***

Seam strength tests were conducted using a Zwick Roell Z010 universal yarn and fabric strength testing machine, with 3 repetitions. The tests were performed according to the TS EN ISO 13935-1 standard, which determines seam strength using the strip method. For the knitted fabrics with high stretch properties containing elastane used within the scope of this study, the distance between the clamps was set to 100 mm and the test speed was adjusted to 100 mm/min. Three samples each, measuring 20 cm x 6 cm, were sewn from the conditioned fabric in both warp and weft directions.

**RESULTS AND DISCUSSION**

As can be seen from the tables (Table 3,4,5) this study compared the physical properties and seam performance of conventional and recycled polyester single jersey fabrics.

*Table 3: Fabric weight and thickness values*

| Fabric Code | Knit Tpe | Material Type | Weight (g/m²) | Thickness (mm) |
|---|---|---|---|---|
| Fabric 1 | Jersey (crepe) | Conventional | 210 | 0,55 |
| Fabric 2 | Jersey (crepe) | Recycled | 210 | 0,54 |
| Fabric 3 | Jersey (sandy) | Conventional | 210 | 0,59 |
| Fabric 4 | Jersey (sandy) | Recycled | 210 | 0,57 |

*Table 4: Fabric tensile strength and breaking elongation values*

| Fabric Code | Course Direction | | Wale direction | |
|---|---|---|---|---|
| | Tensile Strenght (N) | Breaking Elongation (%) | Tensile Strenght (N) | Breaking Elongation (%) |
| Fabric 1 | 427,41 | 94,36 | 171,94 | 387,33 |
| Fabric 2 | 379,72 | 130,88 | 252,39 | 363,21 |
| Fabric 3 | 387,66 | 148,57 | 206,04 | 332,69 |
| Fabric 4 | 375,42 | 141,57 | 212,81 | 354,22 |

Fabric properties analysis showed negligible differences in weight and thickness between conventional and recycled polyester fabrics. Interestingly, recycled fabrics (K2 and K4) exhibited slightly higher strength and lower elongation compared to their conventional counterparts (K1 and K3). This unexpected result suggests that the recycling process might have positively affected the fiber structure, potentially due to the re-alignment of polymer chains during reprocessing.

The 504 overedge stitch consistently showed the highest strength, followed by the 406 double chain stitch, with the 301 lockstitch typically showing the lowest strength. Cross-direction seams generally outperformed length-direction seams in strength. Higher stitch density (5 stitches/cm) and core-spun polyester thread usage resulted in improved seam strength.

*Table 5: Seam tensile strength values*

| Fabric Code | Seam Direction | Stitch Yarn Type | Seam Density (stitch/cm) | Seam Tensile Strenght (N) | Seam Tensile Strenght (N) | Seam Tensile Strenght (N) |
|---|---|---|---|---|---|---|
| | | | | Lockstitch 301 | Three thread overedge 504 | Chainstitch 406 |
| Fabric 1 | Course direction | D1 | 4 | 57,00 | 189,62 | 205,16 |
| | | | 5 | 111,86 | 192,41 | 318,05 |
| | | D2 | 4 | 91,61 | 247,52 | 209,54 |
| | | | 5 | 101,35 | 177,98 | 330,23 |
| | Wale direction | D1 | 4 | 125,83 | 134,98 | 180,73 |
| | | | 5 | 146,68 | 166,91 | 157,68 |
| | | D2 | 4 | 109,26 | 128,54 | 145,35 |
| | | | 5 | 146,31 | 145,35 | 181,78 |
| Fabric 2 | Course direction | D1 | 4 | 79,24 | 233,93 | 221,84 |
| | | | 5 | 100,66 | 266,87 | 240,35 |
| | | D2 | 4 | 181,72 | 314,45 | 212,57 |
| | | | 5 | 96,59 | 178,51 | 309,37 |
| | Wale direction | D1 | 4 | 142,07 | 158,40 | 218,31 |
| | | | 5 | 176,13 | 157,73 | 232,27 |
| | | D2 | 4 | 132,18 | 128,54 | 198,50 |
| | | | 5 | 200,45 | 199,00 | 228,08 |
| Fabric 3 | Course direction | D1 | 4 | 96,01 | 186,81 | 174,83 |
| | | | 5 | 135,24 | 168,56 | 266,10 |
| | | D2 | 4 | 113,54 | 201,03 | 216,66 |
| | | | 5 | 124,89 | 214,07 | 287,48 |
| | Wale direction | D1 | 4 | 148,08 | 174,56 | 174,76 |
| | | | 5 | 182,19 | 173,48 | 186,35 |
| | | D2 | 4 | 125,40 | 183,77 | 197,01 |
| | | | 5 | 196,97 | 161,92 | 222,41 |
| Fabric 4 | Course direction | D1 | 4 | 92,87 | 224,42 | 204,83 |
| | | | 5 | 126,47 | 211,92 | 236,59 |
| | | D2 | 4 | 101,06 | 218,38 | 226,14 |
| | | | 5 | 125,30 | 210,22 | 265,69 |
| | Wale direction | D1 | 4 | 149,81 | 176,52 | 184,46 |
| | | | 5 | 175,10 | 174,66 | 184,85 |
| | | D2 | 4 | 142,41 | 171,15 | 170,35 |
| | | | 5 | 176,96 | 170,02 | 177,95 |

## CONCLUSION

The results provide valuable insights for sustainable textile production. Seam strength tests revealed that recycled polyester fabrics generally had comparable or slightly higher seam strength than conventional fabrics, which is promising for their use in garment production.

Recommendations for textile companies include:

1. Consider using recycled polyester fabrics to meet sustainability goals, as they demonstrate comparable or even superior performance in some aspects.
2. Choose stitch types based on required strength: 504 overedge for high strength, 406 double chain for medium strength, and 301 lockstitch for low-stress areas.
3. Prioritize cross-direction seams where possible.
4. Use higher stitch density (5 stitches/cm) for high-stress areas.
5. Opt for core-spun polyester thread to enhance seam strength.

This study demonstrates that recycled polyester fabrics can perform comparably to, or even better than, conventional fabrics when appropriate sewing parameters are selected, strongly supporting the textile industry's sustainability efforts.

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# DRYING TEMPERATURE OPTIMIZATION OF PVDF-ZNO POROUS PASSIVE RADIATIVE COOLING FILMS

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**ABSTRACT**

Passive radiative cooling (PRC) materials enabling personal thermal management other than space cooling have taken attention of many scientists because of its social, environmental, and economic advantages. Among PRC materials, porous nanocomposite structures produced by non-solvent induced phase separation (NIPS) method including reflective particles have gained popularity with the hierarchical micro-nano pores enhancing solar reflectivity and thermal emissivity. Herein, PRC polyvinylidene fluoride (PVDF) (10 wt.%) porous nanocomposite films including zinc oxide (ZnO) nanoparticles were produced by NIPS, adjusting the percentage of water (3-7%) within the solvent-nonsolvent-water system. Optimization was carried out in drying temperature (120°C, 60°C, 20°C) of the porous nanocomposite films to get more heterogeneous and transparent structure with the minimum energy. Results showed that, optimum micro-nano hierarchical porous structure was obtained with 7% water according to SEM analyses, but the optimum film color could not be obtained for both 120°C, 60°C drying temperatures besides a possible deterioration. Lowering the drying temperature to 20°C, keeping the hierarchical porous structure, the minimum color deterioration was also obtained with a slightly higher cooling effect evaluated by a hotplate system including a sun simulator lamp. Summing up, a cooling effect of 3.85°C was obtained with the porous nanocomposite film dried at 20°C by a cost-efficient and eco-friendly manufacturing path.

**Key words**: nanocomposite, radiative cooling, porous film, phase-separation, eco-friendly

## INTRODUCTION

The current global energy crisis and escalating environmental concerns have intensified the demand for novel thermal management materials and technologies with low to zero carbon emissions, aiming to overcome the existing impasse. Passive radiative cooling (PRC) materials enabling passive cooling of surface objects without any energy consumption or greenhouse gas release, are attracting attention as promising materials with advantages of environmental impact, energy savings and total wellbeing of the population (Liu et al., 2022). Spectrally selective materials with simultaneous high solar reflectance and infrared thermal emittance display passive cooling performance by reflecting sunlight and emitting thermal radiation. Due to the promise of these materials, a variety of materials, including multilayer photonic structures, composite structure with distributed particles, metamaterials, biomaterials, and bio-inspired materials have been extensively explored in recent decades (Tsang et al., 2024). However, these materials have been developed using sophisticated and costly technologies/methods as well as unsuitable large-scale production, including spin coating, solvothermal method, electron beam deposition etc. Moreover, few studies focus on fabricating low-cost, highly efficient, and robust PRC materials by a facile and environmentally friendly method for further practical applications. To tackle these challenges, new effective and environmentally friendly cooling technologies achieving an optimal balance between structural designs and processing costs, need to be put on the agenda. In this manner, porous radiative cooling materials attract attention owing to their easy-processing, low cost, and outstanding cooling performance, which greatly advance large-scale radiative cooling applications. Porous radiative cooling materials can strongly reflect solar irradiation based on multiply Mie scattering effect, meanwhile possess efficient mid-infrared emission due to molecular vibration absorption of polymer, thereby achieving high solar reflectivity and mid-infrared emissivity (Xiang et al., 2021). Effective solar reflectivity and emissivity can be achieved by rationally adjusting the size and distribution of the pores within the structure. Recently, phase separation, especially NIPS method with advantages of cost-effectiveness and wide applicability, is effective for fabricating tunable micro-nano hierarchical porous structure in polymer films. Besides, compositing polymers with dielectric micro/nanoparticles such as ZnO, titanium dioxide ($TiO_2$), magnesium oxide (MgO), aluminum oxide ($Al_2O_3$), $SiO_2$ etc., enhanced their selective spectral response and offer advantages such as affordability, ease of fabrication, scalability, and broad spectral tunability (Du et al., 2023). Among these particles and polymers, PVDF polymer has a high emissivity resulting from the stretching and deforming vibrations of C-F bonds in the window range (8-13 µm) as ZnO particles show high sunlight reflectance and low absorbance of sunlight (Zhu and Feng, 2021). These intrinsic material properties render the combination of ZnO and PVDF uniquely suitable as the radiation-selective materials for PRC.

Here, nanocomposite films including PVDF polymer matrix and ZnO particles were produced by NIPS method using solvent/co-solvent/non-solvent system. A hierarchical morphology, comprising of nanospheres and nano-micropores randomly dispersed throughout a polymer matrix, was formed that employs multiple scattering effect. Besides adjusting non-solvent (water) content for porous film, drying temperature (120°C, 60°C, 20°C) was optimized for more heterogeneous and transparent structure via minimum energy.

## MATERIALS and METHODS

### Materials

PVDF (10 wt.%) porous nanocomposite films having hierarchical micro-nano pores were prepared with NIPS method, a simple and low-cost method by drying temperature optimization. PVDF (Kynar 720, Arkema Company, France), a spectrally selective polymer with a high emissivity resulting from the stretching and deforming vibrations of C-F bonds in the window range (8-13 µm) was used as matrix material. ZnO (90 nm, Nanografi, Türkiye), as nanofiller, stands out as a material with not only high refractive index $n \approx 2$ but also very little absorption from visible wavelength (400 nm) to mid-infrared wavelengths (16 µm) (Zhu and Feng, 2021). N, N dimethyl acetamide (Sigma Aldrich) (DMAc) was used as the solvent, and acetone (Acros Organics) (ACE) as the co-solvent without any purification. Sorbitan monostearate (Span60, Sigma Aldrich) was used as surfactant to get more homogenous nanoparticle dispersion. In one-step non-solvent-induced phase separation film formation method, deionized water, was used as non-solvent.

### Methods

NIPS method including multi-solvent (solvent, co-solvent) (DMAc, ACE) and non-solvent (water) was used to create hierarchical micro-nano porous composite film structure optimized by water content and drying temperature. First, porous PVDF film was produced by dissolving PVDF powder at 10 wt.% in mixture of DMAc and ACE at 50°C for 6 h under 400 rpm magnetic stirring. Then appropriate amounts of water (0%, 3%, 5%, and to 7%) were added dropwise by a syringe pump at a feeding rate of 0.2 ml/min under magnetic stirring for another 1 h until it became clear under heating conditions. In the last step, the solutions were cast in the form of a thin layer of 300-400 µm thickness into petri-dishes and dried for 6 h at different temperatures (120°C, 60°C, 20°C) to get more heterogeneous and transparent structure with minimum energy. For producing porous nanocomposite films, ZnO nanoparticles were included in 10 wt. % of PVDF-solvent/co-solvent (DMAc and ACE) solution with 2 wt. % content under mechanically stirring for 2 h. To achieve a more homogeneous particle distribution in the PVDF polymer matrix, Span60 (a non-ionic surfactant) was added at a ratio of 1:2 with respect to the nanoparticle, and the solution was sonicated.

Porous structure and morphologies of the PRC PVDF films were characterized by scanning electron microscope (SEM, Fei Quanta FEG 250) with an accelerating voltage of 20 kV and 10 µA current. Cooling performances of the PVDF films was tested using a designed set-up of a simulated skin (34°C) with 8 K-type thermocouples, data acquisition and recording system (5-s frequency) under simulated solar irradiation. The film was placed on the hot plate that can precisely remain constant at the skin surface temperature of 34°C with face side up under the sun simulator lamb at a distance of 25 cm. The irradiation intensity on the surface was controlled at 600 Wm$^{-2}$ with environmental temperature of 22-26°C and relative humidity of 50%. The temperatures of the films were measured for 1 min while stabilizing followed by the heating (lamp on) and cooling (lamp off) stages of 10 min each. At least three replications were made for each film.

## RESULTS and DISCUSSIONS

### Optimization of Water Content Based on Porous Structure

Both size and shape of the pore are involved in the scattering phenomenon and dramatically changes the radiative cooling performance. Morphology and cross-sections of the films dried at 120°C were analyzed using SEM and images were given in Figure 1. Figure 1a shows a dense film structure without any pores, produced without water. With water content of especially 3% and 7%, 3% being higher, porous structure formed on film surfaces as seen in Figure 1b and d. The porous structure can be attributed to the multi-stage solvent displacement such as DMAc (solvent) evaporation accelerating with ACE (co-solvent). Moreover, solvent polarity and solubility, hence phasing out of PVDF polymer from solvent/non-solvent (water) system may also be affective on this system.

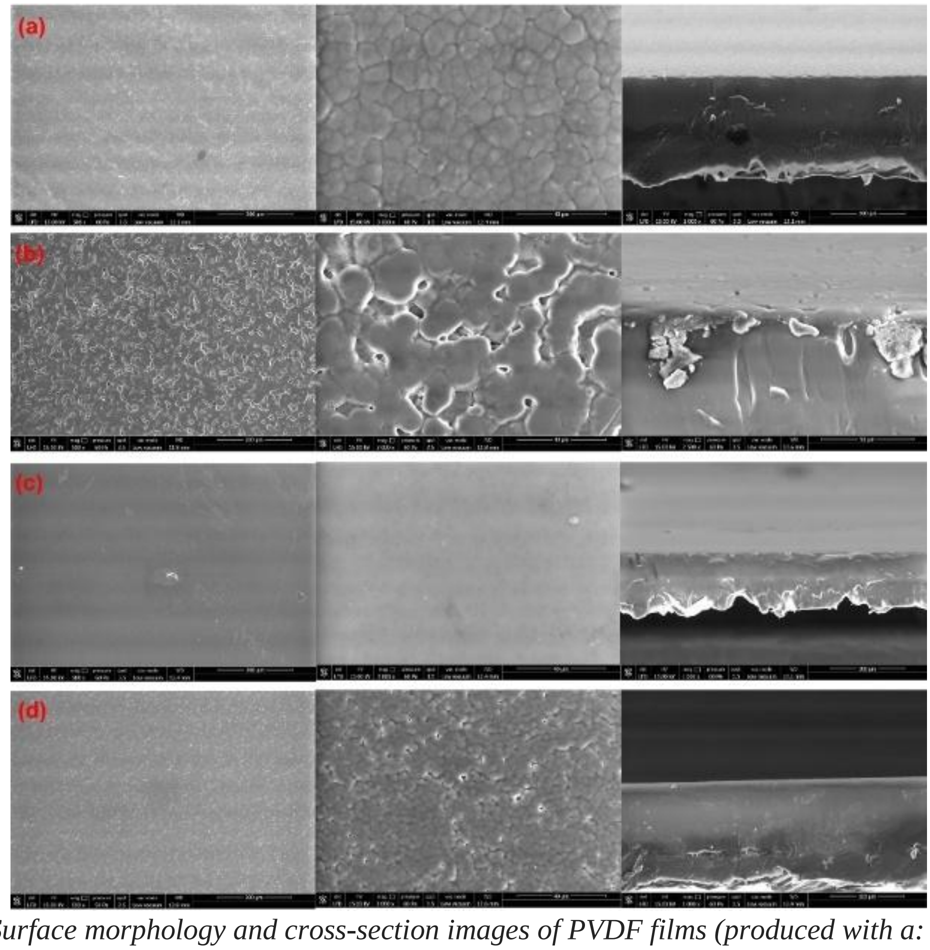


*Figure 1: Surface morphology and cross-section images of PVDF films (produced with a: 0, b: 3%, c: 5%, d: 7% water contents) (Memis and Kaplan, 2024)*

According to the test results of passive cooling performances seen in Figure 2, adding water into solvent system resulted in higher cooling performance owing to the porous structure formed. The cooling effect of the films increased with water content except for 3% and reached a maximum of ~6.23°C compared to their nonporous forms. It is interesting to note that films produced by adding 3% water had higher temperature compared to non-porous films although a porous structure is obtained. Based on these results, the amount of water in the multi-solvent system for porous structure was optimized as 7%.

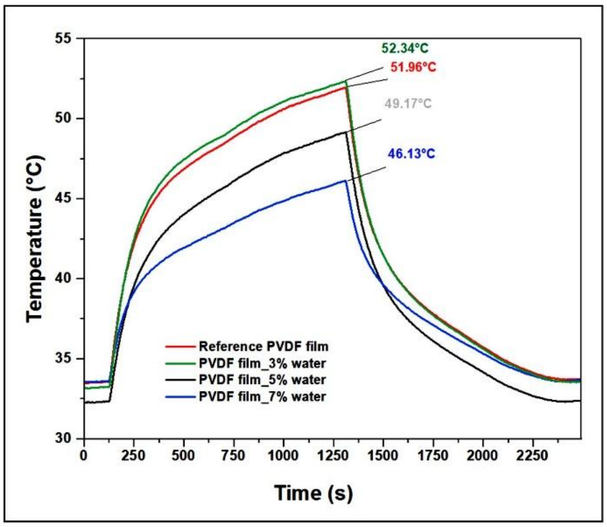


*Figure 2: Cooling performance of PVDF films with varying water content-hotplate*

**Optimization of Drying Temperature**

In addition to adjusting the amount of water content in the multi-solvent system depending on the porous structure, the drying temperature of the films was also optimized to get more heterogeneous pore structure and optimum color with minimum energy. Therefore, films including 7% water in the multi-solvent system were dried at varying temperatures (20, 60, and 120°C) and their transparencies, cooling performances, and porous structures were investigated. According to the digital photographs given in Figure 3, the color of the films deteriorated could not be obtained for both 120°C (Figure 3a) and 60°C (Figure 3b) drying temperatures besides a possible color deterioration. Lowering the drying temperature to 20°C (Figure 3c), keeping the hierarchical porous structure seen in Figure 4, no color deterioration was detected.

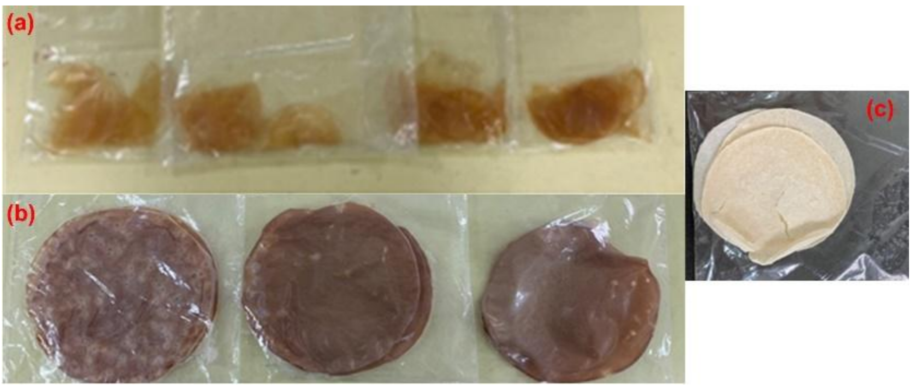


*Figure 3: Photographs of PVDF films dried at different temperatures (a) 120°C, (b) 60°C, (c) 20°C*

With the addition of ZnO, a richer porous structure was obtained (Figure 4) because ZnO affected the continuity of the polymer-enriched phase (Ma et al., 2024) through its penetration into clusters of the film. With nanoparticle addition, micro-voids and uneven surfaces on the coating surface formed in the film structure. Moreover, sizes of the pores on the microporous wall changed more to nano-size owing to slowing down of solvent evaporation which delays the phase inversion process with higher viscosity (Qi et al., 2022). On the other hand, micro-voids are formed within the film because of a surface-driven phase separation and crystallization induction. The mentioned crystallization process starts consuming the polymer at the surface due to the exothermic crystallization and leads to a faster solvent crystallization and micro-voids in the nearby regions (Cardoso et al., 2015).

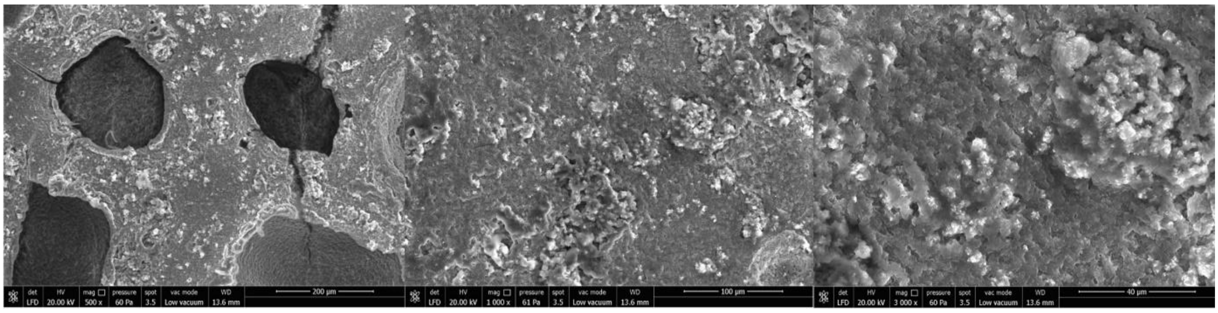

*Figure 4: SEM images of PVDF-ZnO films dried at 20°C*

During decreasing steps of the drying temperature ZnO is incorporated within the PVDF films and dried at 20°C and 60°C. Comparing the cooling performances of all optimized non-porous and porous films (Figure 5), a temperature drop of 6.23°C was obtained for the porous/non-porous forms dried at 120°C. For 20°C drying temperature, the only pore effect created a temperature drop of 1.77°C was obtained a further enhancement was obtained by the ZnO incorporation 3.85°C totally (a 2.08°C enhancement with ZnO). The nanocomposite films dried t 60°C gave 2.38°C higher temperatures when compared with the ones dried at 20°C. Despite higher cooling effect obtained at 120°C drying temperature, the optimum drying temperature was optimized as 20°C because of the color/probable mechanical deterioration and higher energy demand of the films dried at 120°C. The temperature drop of nanocomposite obtained at 20°C drying temperature (3.85°C) may be due to the micro-nano multi-stage porous structure of composite films, enhancing the Mie scattering of sunlight and reducing the sunlight energy absorption of the film (Qi et al., 2022).

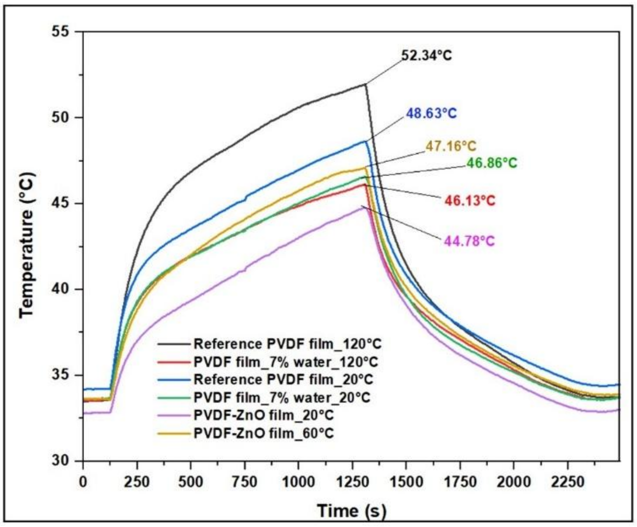


*Figure 5: Cooling performance test results of PVDF films dried at different temperature*

## CONCLUSIONS

In this study, porous PVDF nanocomposite films with ZnO incorporation were prepared using a simple NIPS method with multi-solvent system for effective daytime radiative cooling. The optimal conditions for the preparation of porous PVDF-ZnO nanocomposite films were determined as 7% water content (as non-solvent in the multi-solvent system) and 20°C drying temperature. The resulting nanocomposite film has hierarchical porous structure with micro-nano pores and micro-voids without color and structural deterioration. These nanocomposite films exhibited a maximum cooling temperature of 3.85°C under a solar irradiance of 600 $Wm^{-2}$ when compared to its non-porous form. This result can be attributed to the solar reflection by the porous structure and ZnO nanoparticles as a result of scattering effect and the outward radiation by the PVDF matrix. This work presents a simple-to-prepare, low-cost, eco-friendly porous PVDF radiative cooling film with ZnO, providing a viable strategy for energy management.

### ACKNOWLEDGMENTS

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# DETECTION AND CLASSIFICATION OF FABRIC DEFECTS WITH AN INNOVATIVE MODEL AND PERSPECTIVE

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## ABSTRACT

Fabric defects arising from production processes or material inconsistencies are not always identified during manual quality control, which diminish the quality standards of finished garments in clothing and negatively impact profitability. Designing a model based on convolutional neural networks (CNNs), a prominent deep learning technique, might facilitate defect detection and classification. Within the scope of this study, a CNN model was designed with the aim of classifying fabric images into five categories—'Yarn Defect,' 'Hole and Cut Defect,' 'Color and Stain Defect,' 'Foreign Object Defect,' and 'Normal'—without considering the structural differences between woven and knitted fabrics. The designed model was trained on the data taken from TILDA dataset for its ability to accurately detect and classify fabric defects. Performance metrics, including accuracy, specificity, recall, and precision were employed to measure the model's efficacy, with results indicating a 96.77% accuracy rate. The model's success was further corroborated by the Loss-Accuracy/Epoch and Precision-Recall curves. This model represents a foundational step for a thesis study developing a more advanced system that can account for the structural differences between woven and knitted fabrics in future research phases.

**Key words**: Fabric Defect Detection, Fabric Defect Classification, Deep Learning, Convolutional Neural Networks (CNNs)

## INTRODUCTION

Countries view the textile and apparel industry as crucial due to the import and export opportunities it provides, as well as its contribution to employment within the country. In order to sustain these advantages, companies need to increase their profitability. At this point, maintaining fabric quality and reducing non-value-added process time are essential.

Fabric defects, which may occur due to the machine issues, material-related problems, or personnel carelessness, are the most important factors affecting the sustainability of fabric quality. While some of these defects can be prevented if noticed in time, fabrics with defects cannot be corrected after production. If the defects are unnoticed, they can cause quality problems in the final products, leading to a price reduction of around 45%-65% (Kumar, 2008). In addition to the fabric defects, the traditional manual quality control process conducted after production is seen as a non-value-added activity due to its long duration and its susceptibility to errors. This method can achieve only 60%-75% accuracy (Almeida et. al., 2021), and not all fabrics in an order can be subjected to quality control due to time and cost constraints. With this traditional method, it is not possible to evaluate the quality of all fabrics, which can result in defects going undetected and causing issues during clothing production. In light of these points, automatic fabric defect detection can help prevent human errors and speed up traditional quality control process, making it more efficient.

Numerous studies in the literature focus on automatic detection of fabric defects. Among them, deep learning-based studies occupy a significant place due to the various advantages they provide. Convolutional neural networks (CNN) are widely used in deep learning-based approaches. Therefore, a preliminary study, which aims to design a CNN model to detect and classify fabric defects is planned. Within the scope of this study, it is aimed that the designed CNN model creates a foundational step for a thesis study in which a more advanced model design that considers the structural differences in woven and knitted fabrics.

## THEORY

### Fabric Defects

A fabric defect can be considered as a flaw on the manufactured fabric surface (Hanbay et al., 2016). In the literature, 235 different defects and their reasons have been reported. Although the classification of fabric defects varies across different sources, Cotton Incorporated (2023) categorized fabric defects into six groups. These six classes are ‘warp-wise defect,’ ‘filling-wise defect,’ ‘isolated defects (unevenness, neps, slub, fly),’ ‘pattern defects,’ ‘finishing defects,’ and ‘printing defects.’ In addition, a review of studies focused on automatic fabric defect detection and classification reveals that fabric defects can be generally collected under four classes: 'Yarn Defect,' 'Hole and Cut Defect,' 'Color and Stain Defect,' 'Foreign Object Defect' (Birsen & Sarıçam, n.d.).

### Deep Learning

The term ‘deep learning’ was introduced by Aizenberg, with significant developments made by Hinton in training multilayer neural networks, allowing for fine-tuning of parameters in trained layers through a supervised feedback mechanism. Various deep learning architectures, such as CNN, RNN, LSTM, Generative Models, RBM, and DBNs, are designed for different tasks (Kahraman & Durmuşoğlu, 2022). It has been demonstrated that different deep learning architectures can be applied for fabric defect detection and classification. Among these, CNNs offer advantages over other architectures in terms of quality, robustness, performance, and real-time capabilities. CNN also provides superior feature extraction, greater flexibility for architectural changes and a finer structure for small samples.

Architecturally, CNN is a type of artificial neural network commonly used in feedforward, supervised learning, comprising six different types of layers. These layers, in sequence, are the input layer, convolution layer, pooling layer, flattening layer, fully connected layer, and output layer. The initial layer where the network receives data provided from external sources. The convolution layer then performs point multiplications by moving a set of filters, also known as kernels, in order to extract features from the input data (Purwono et al., 2023). The resulting feature maps indicate which areas of the input data are significant. To reduce the number of parameters processed, the pooling layer performs a down sampling process (Gholamalinezhad & Khosravi, n.d.). The data from the pooling layer is then flattened into a one-dimensional vector by the flattening layer (Yang et al., 2020). Subsequently, each neuron in the fully connected layer receives the processed data to compute the output. At the end, the output layer ensures that the data supplied as input is classified in accordance with the probability distributions created for classification tasks (Guo vd., 2017). Additional layers, such as dropout layers, can be integrated to the structure to enhance the performance. For instance, the dropout layer helps prevent overfitting by ‘forgetting’ certain features, thus improving the model’s generalization ability. A general CNN model is shown visually in Figure 1.

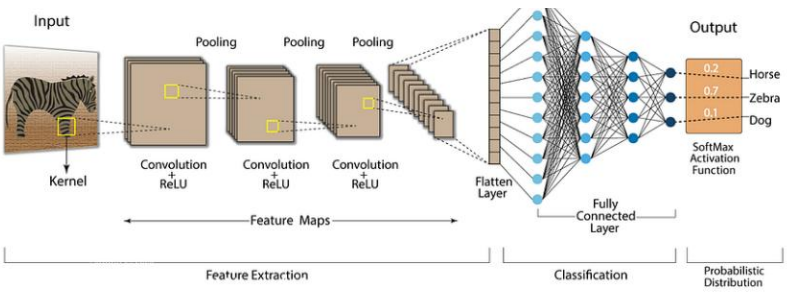


*Figure 1: A General CNN Structure (Pratham, 2023)*

**METHODS**

In this study, the steps outlined in the flow diagram in Figure 2 were followed sequentially to accomplish the study's objective. Accordingly, a CNN model was designed to classify the defected fabric images into five categories – 'Yarn Defect,' 'Hole and Cut Defect,' 'Color and Stain Defect,' 'Foreign Object Defect,' and 'Normal' – without considering the structural differences between woven and knitted fabrics.

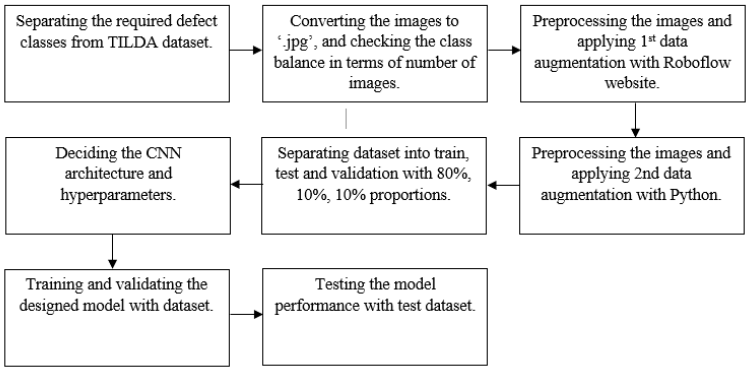

*Figure 2: Flow Diagram for Designing CNN model and Performance Testing*

In the first step, the selected dataset, TILDA, created by the University of Hamburg (Computer Vision Group, n.d.) was analyzed and usable defect classes separated. The dataset contains eight distinct defect classes, including a defect-free fabric structure and seven defect classes. Accompanying each defect image is a text file containing a description. However, for the purpose of this study, only fabric-related defect classes which are 'No Defect,' 'Hole and Cut Defect,' 'Yarn Defects,' 'Foreign Materials on The Fabric Texture,' are utilized to create the dataset by separating irrelevant classes. After analyzing the dataset, the image files extensions were converted from TIFF to JPG to ensure compatibility with the designed model. Class balance was also monitored to guarantee that the model was trained with an equal number of images from each class, preventing bias toward any particular class. Consequently, approximately 50 image files were maintained for each class, totaling 1.999 images, with each image sized at 768 by 512 pixels.

Preprocessing steps, which included auto-orienting the images, converting them from color to grayscale, and resizing them to 416 by 416 pixel through stretching were applied. Later, image augmentation – an approach that transforms images to enhance diversity – was employed to increase the dataset size. The reason is that, CNN models require a substantial amount of data to effectively extract features. Insufficient data can lead to issues such as bias, poor performance and lack of generalizability and transferability due to overfitting (Safonova et al., 2023). In order to ensure that there is enough data, five types of transformations were implemented via Roboflow website: horizontal and vertical flips, rotation, horizontal and vertical shearing, saturation adjustments and noise addition. Through these augmentations, the total number of images was increased to 5,997. In the next step, a second augmentation was applied by using Python, as the Roboflow website limits the augmentation amount by three images per original image. In the second augmentation phase, two types of augmentations were applied: random brightness adjustments, and random contrast adjustments. As a result of this second augmentation, the total number of images increased to 17.991 images, with approximately 3.600 images per class. After completing the augmentation, the dataset was split into training, validation and test sets with proportions of 80%, 10% and 10%, respectively. During this process, class balance was maintained to ensure that the model is not biased towards any of the classes.

After the dataset preparation step, an overfitting model was deliberately attempted in the model's design process. This approach was chosen because an effective model lies between an underfit and an overfit.

Overfitting was induced by increasing the number of layers and the number of epochs, which are iterations of training in the model. Afterwards, hyperparameter tuning and regularization techniques were applied. Dropout was introduced, and extra layers were removed to optimize the model's performance. The activation function, the loss function and the optimization procedure were chosen for the model. The ReLU activation function – commonly utilized in convolutional layers due to its computational simplicity – was applied while the Softmax activation function was used in the output layer, which is employed in multiclass classifications problems. The loss function selected was 'categorical cross-entropy,' appropriate for classification problems involving more than two classes. For optimization, the 'ADAM' algorithm was employed due to its computational efficiency and lower memory requirements. Additionally, the 'Early Stop' algorithm was incorporated, which monitors the validation set's loss values, and stops the training after a certain iteration if there is no improvement is observed, thus preventing overfitting. 'L2 Regularization', was used for preventing overfitting by decreasing the weights, so that the model is not overly sensitive and affected by small changes in dataset. The final model structure and the selected hyper parameters depicted in Table 1, and Table 2 respectively.

*Table 1: The Designed CNN Model Structure Summary*

| **Layer (type)** | **Output Shape** | **Param #** |
|---|---|---|
| input_layer_7 (InputLayer) | (None, 416, 416, 3) | 0 |
| rescaling_7 (Rescaling) | (None, 416, 416, 3) | 0 |
| conv2d_14 (Conv2D) | (None, 414, 414, 32) | 896 |
| conv2d_15 (Conv2D) | (None, 412, 412, 32) | 9,248 |
| max_pooling2d_7 (MaxPooling2D) | (None, 206, 206, 32) | 0 |
| flatten_7 (Flatten) | (None, 1357952) | 0 |
| dense_21 (Dense) | (None, 32) | 43,454,496 |
| dropout_7 (Dropout) | (None, 32) | 0 |
| dense_22 (Dense) | (None, 32) | 1,056 |
| dense_23 (Dense) | (None, 5) | 165 |

*Table 2: Hyperparameters of Designed CNN*

| **Parameters** | **Value** |
|---|---|
| Number of neurons in hidden layers | 32 |
| Size of kernels in convolutional layers | (3x3) |
| Size of filters in pooling layers | Maximum pooling (2,2) |
| Dropout rate | 0.4 |
| Learning rate | 0.001 (default) |
| L2_regularization rate | 0.02 |
| Early stop patience | 100 |
| Batch size | 32 |
| Number of epochs | 200 |

According to the steps provided and the proposed CNN model design, tests were conducted to demonstrate the model performance.

**FINDINGS & DISCUSSION**

In order to support to defect-free fabric production, and shorten the duration of lengthy processes like quality control in textile and apparel industry, a model was designed using the CNN architecture – one of the most widely used methods in fabric defect detection and classification within deep learning models. Tests were conducted on the test set to demonstrate the model's performance, which was supported with different performance metrics including training and test accuracy, specificity, recall, and precision metrics, precision-recall curves, and accuracy-loss curves,

The performance of the designed CNN model was first evaluated by checking the training set's results. Accordingly, the model was able to demonstrate 99.73% training accuracy. In addition to controlling the designed model's resultant training accuracy, the model's performance most importantly measured by using a test set, which consists of 1.799 images. The model demonstrated strong performance, achieving a test accuracy of 96.77%. Additional performance metrics such as specificity, recall, and precision were calculated. Each providing an outstanding result with the values of 100%, 96.72%, and 96.76% respectively. These metrics indicate that the model is highly capable of accurately distinguishing between different classes. However, there was a slight difference between the train and test accuracies. This might mean that the model learned the training data well, but not generalize on unseen data. Therefore, these performance results may be misleading, and the model performance was further assessed by curves like precision-recall and accuracy and loss curves.

Precision-recall curve of the designed model was demonstrated in Figure 3. This curve enables the evaluation of the model's performance across different defect classes. A well-performing model typically shows a precision-recall curve where the area under the curve is maximized, reflecting high precision and recall. In this case, the precision-recall curve demonstrated a robust model, as the area under the curves for all classes were high and nearly equal. This supported the previous performance results of the model, proved the ability to effectively classify the fabric defects and its overall robustness.

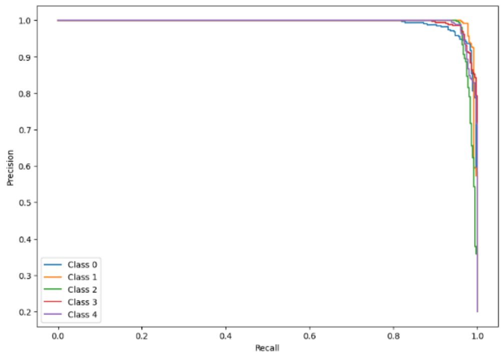


*Figure 3: Precision-Recall Curve of Proposed CNN Model*

Accuracy and loss curves for epochs of designed CNN training was demonstrated in Figure 4. The overfitting possibility of model can be better observed with the accuracy and loss movements of training and validation data during training. As observed from Figure 4, both validation and training losses initially decrease while both validation and training accuracies increase, indicating that the model was learning efficiently. However, as the epochs progress, training accuracy continued to increase gradually, while validation accuracy rose rapidly and frequently fluctuated. On the other hand, although training loss continued to decrease gradually, validation loss decreased rapidly and plateaued at the end of the training without showing signs of improvement, thereby increased the gap between training and validation loss. These may indicate that the model has learned the training set well, but not be able to generalize in unseen data.

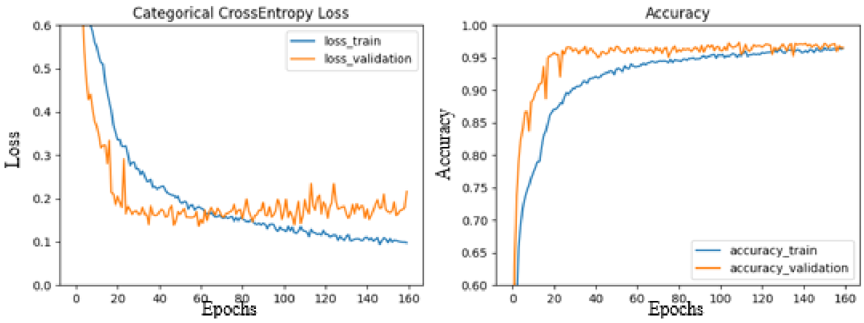


*Figure 4: Accuracy and Loss Curves for 200 Epochs of CNN Training*

## CONCLUSION & IMPLICATIONS

Countries benefit greatly from the textile and apparel industries, where maintaining profitability requires high-quality production. Defective manufacturing is significant hindrance to this quality. As traditional quality control methods can be both time-consuming and costly, often not adding value. Therefore, there is a need for defect-free and efficient quality control processes that eliminate human error.

Numerous studies focus on the automatic detection and classification of fabric defects. CNN, being one of the most widely utilized deep learning method due to its advantages in fabric defect detection and classification is mostly preferred. Therefore, a preliminary study was proposed where the model detects and classify fabric defects using TILDA dataset. The model's performance was evaluated using metrics such as accuracy, precision, recall, and specificity. Additionally, tools like precision-recall curves and accuracy/loss-epoch curves were employed to validate the model's efficacy in detecting and classifying fabric defects. As a result, the model achieved a test accuracy of 96.77%, demonstrating superior precision, recall, and specificity, along with a precision-recall curve that illustrated its ability to effectively distinguish between different defect classes. However, the difference between the training and test accuracy, along with the loss and accuracy movements of the training and validation sets during training, indicated that the model may be overfitting the training dataset and failing to generalize to unseen data.

The completion of this model made it possible to increase the 60-75% success rate attained in traditional quality control methods to 96.77%. However, it is important to note that the performance evaluation of this model was conducted using only TILDA dataset, and there was a possibility of overfitting. For future studies, it is planned that the model's performance will be assessed on different fabric datasets, and the model will be fine-tuned by using different hyperparameters. As a result, this study served as the basis for a thesis study that aimed to create a more complex model that accounts for the structural differences between knitted and woven fabrics.

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# A GLANCE TO VARIOUS REGENERATED CELLULOSIC FIBERS

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## ABSTRACT

This paper gives brief information about various regenerated rayon cellulosic fibres, with a particular focus on their intrinsic properties and the environmental impacts associated with their production. The distinction between fast fashion, which is characterized by low prices and rapid production, and slow fashion, which prioritises higher quality and sustainable products, is elucidated. Here, some environmental effects and characteristics of various cellulosic rayon fibres, including Lenzing Ecovero, viscose, lyocell, and seacell, are given. This manuscript advocates for companies to transition to eco-friendly production methods and develop strategies that align with consumer demands for sustainability in textile practices. Due to the sustainable properties of regenerated cellulose fibers, both their usage amounts and usage diversity are expected to increase in the coming period.

**Key words**: Rayon, Viscose, Fiber, Regenerated Cellulosic Fibers

## INTRODUCTION

The term 'green production' denotes a novel approach to manufacturing that entails the integration of pollution control measures throughout the production process. This strategy is designed to minimise the adverse impact of industrial activities on the natural environment and human health. The objective is to achieve economies in energy consumption, reduce waste and pollutant emissions, utilise advanced production technologies and ensure the efficient use of resources. Green textiles and garments are subject to a number of regulatory and quality control standards. In order to achieve the eco-green status of textiles and garments, it is essential that all industries enhance their cooperation and management practices, extending from the sourcing of raw materials to the production of the final product (Uludağ, 2020; Cebeci, 2013). In 1992, the European Union established the standards that must be met in order to qualify for the Eco-label. Experimental and empirical evidence indicates that the majority of damage to the natural environment is attributable to the production and consumption of goods and services. The objective is to establish a standard for companies, manufacturers and consumers to address this issue through the implementation of eco-label standards. The most significant benefit of eco-label applications is the heightened awareness among the general public (Uludağ, 2020; Cebeci, 2013).

In the process of sustainable development, resource utilization can be considered as the most important saving tool, considering the direct relationship of raw materials with ecology as a resource in production means. In the selection of resources in the sustainable production process, it is very important that they can be found in nature, that they require little energy as input and output during production, that they are suitable for long-term use, that they cause the least damage to the environment, that they can be recycled and that their use is appropriate in international and national legislation. If the resource used in production is a product that is naturally scarce or difficult to process, alternatives must be considered (Cebeci, 2013).

This article discusses some of the salient features and environmental impacts of different cellulosic rayon fibers, including viscose, lyocell, seacell, and Lenzing Ecovero. This article encourages businesses to switch to environmentally friendly production techniques and create plans that meet consumer demands for sustainable textile operations. Here, in this publication, firstly, Comparison of fast and slow fashion will be made. Then, information about Various Sustainable Rayon Fibres Alternative to Traditional Fibres will be given.

## COMPARISON OF FAST AND SLOW FASHION

The concept of fast fashion can be described as a business model that has rapidly taken over the entire global industry. Fast fashion is a concept that emerged in the United States in the 1980s and covers the rapid production of products from design to store and instant response to market needs (Mangır, 2016). Until the end of the 80s, fashion retailers offered two collections per year, spring/summer and autumn/winter. However, in the 90s, this situation changed completely and the era of "super-fast, super cheap" began (Eser et al., 2016). Brands such as Zara, Benetton, GAP and H&M have adopted this business model. Overconsumption is one of the main characteristics of fast fashion (Mangır, 2016; Yücel & Tibet, 2018). Slow fashion is an approach that has emerged to reduce the impact of fast fashion on production resources and the environment within the framework of sustainability. It is related to the concept of 'sustainable design' in terms of individual and social-cultural balance and environmental needs (Mangır, 2016). In the early 2000s, the concept of slow fashion focused on the fashion industry and concepts such as transparency, sharing economy, recycling and upcycling (honour). It first emerged with the slow food movement. Again, in 'slow cities', it emerged from the perspective of people who wanted to get away from the overwhelming rush of everyday life. The Slow Food movement has also shown that people are willing to pay for individuality. This has been reflected in the fashion industry in the form of slow fashion. Collections designed with this in mind use the highest quality fabrics in the simplest shapes. The idea of slow fashion is based on balance. It is true that quality comes at a price, and according to this logic, longer lasting products in the sector are sold to consumers at a higher price and the use of materials is reduced by half without any loss (Cebeci, 2013). A comparison of fast and slow fashion is given in Table 1;

*Table 1. Comparison of slow and fast fashion (Mangır, 2016; Cebeci, 2013; Yücel & Tibet, 2018)*

| Fashion Type | Slow Fashion | Fast Fashion |
|---|---|---|
| **Strengths** | • Improved quality of life for employees<br>• Product quality increases<br>• Increased product lifetime<br>• Consumption amounts are decreasing | • Fast fashion responds quickly to consumers' wishes<br>• Low price<br>• Highly profitable in global markets |
| **Profit Model** | • Value-added products are used<br>• A small amount of high product is made<br>• Consumers buy few but high-quality products | • There is voluminous budget model<br>• Fast and inexpensive products in large quantities |
| **Challenges** | • May not be suitable for low speed companies with small quantities<br>• Products are much more expensive than other products | • Fast production leads to disregard for working conditions<br>• Low quality and low prices create fashion pollution. |
| **Style** | It is the singular style that reflects individual identities in fashion | Appeals to the latest trends in terms of fashion and symbolizes belonging to a group |

The concept of green production is fundamentally different from the fast fashion model that dominates the industry. Green production aims to reduce environmental impact throughout the production process, focusing on pollution control, energy efficiency and resource management. In contrast, fast fashion emphasises rapid production and consumption, often leading to overconsumption and significant environmental degradation. This model, which emerged in the 1980s, prioritizes low-cost, fast-produced clothing, contributing to excessive waste and resource depletion. The production methods of sustainable fibres are more in line with the principles of green production and promote ecological balance.

## VARIOUS SUSTAINABLE RAYON FIBERS ALTERNATIVE TO TRADITIONAL FIBERS

In order to be successful in sustainable textile studies, it is recommended that companies should constantly update their product ranges, implement different strategies to stay ahead of their competitors, manage business processes well and intervene in problems immediately, follow consumer trends and produce according to expectations, carry out environmentalist practices by making ecological-based production, reduce risks and increase the profit rate by making cost analyses correctly, increase productivity by making their employees happy and contribute to the continuity of the company (Uludağ, 2020).

In a study, the environmental impacts of the most commonly used fibres in the garment industry were investigated and compared. In the comparison, only the processes of natural and synthetic fibres from raw material to spinning were examined (Eser et al., 2016). According to the results of the study, fibres produced by conventional methods (natural or synthetic) are far behind in the sustainability ranking, while recycled or organic production methods have more positive effects on the environment (Eser et al. 2016). There are also regenerated cellulosic fibres other than cotton. With an annual production volume of about 7.1 million mt, man-made cellulosic fibres (MMCFs) have a market share of about 6.4 percent of the total fibre production volume. Global MMCF production has more than doubled from about three million tonnes in 1990 to about 7.1 million tonnes in 2019 and is expected to continue to grow in the coming years. MMCFs comprise viscose, acetate, lyocell, modal and cupro (www-1).

The textile industry is increasingly focusing on sustainable fibres such as Lenzing Ecovero, Lyocell and Seacell, which are produced using environmentally friendly methods. These fibres are made from sustainably sourced materials and are designed to minimise the environmental footprint compared to traditional textile fibres. Sustainable fibres use recycled or organic production methods that have been shown to have a greater positive impact on the environment than conventional methods, thus contributing to a smaller environmental footprint. A brief description of some of these regenerated cellulosic rayon fibres are given below;

### *Lenzing Ecovero Fibre*

Lenzing has developed EcoVero fibre as an environmentally friendly and traceable viscose fibre based on years of experience in viscose fibre production. Lenzing EcoVero fibre is made from trees from certified sustainable (FSC® or PEFC® certified) forests. EcoVero fibre production has a lower environmental impact (emissions and water) than conventional viscose fibre production (www-2 www-3).

### *Viscose fibre*

The raw material for viscose yarn, abbreviated CV, is viscose wood. Viscose fabric is the general term for fabrics knitted from these yarns (Figure 1). It is the most important and widely used regenerated (recycled) cellulose fibre. Beech grows naturally in Europe, Asia, America, Japan and Turkey. Like cotton, this fiber is made up of cellulose. There is no chemical change in the structure of the cellulose. Under normal conditions, it absorbs 11-14% moisture and can absorb up to 80-120% water due to its high swelling capacity (www-4; Cebeci, 2013). Viscose, which has a soft hand, absorbs more perspiration than cotton, has a slippery texture and a structure that is compatible with the skin (Cebeci, 2013).

*Figure 1. Viscose Fibre (www-5)*

***Lyocell fibre (Tencel)***

The raw material for Lyocell fibres is cellulose. Cellulose is a biodegradable and infinitely available substance. It can be obtained from many trees. The cellulose obtained is chemically extracted, regenerated in an organic solution and converted into fibre (Cebeci, 2013). The origin of the studies on Lyocell fibres is based on the measures taken by European countries to prevent the production of viscose due to the damage caused to the environment by sulphur waste. After many trials, a ready-to-use fiber-making process was developed using a non-toxic amine oxide in a closed cycle with continuous regeneration. This has resulted in a new cellulosic fibre with advantages in terms of renewable resources (Cebeci, 2013). Lyocell fibres available in the market can be counted as Tencel, Tencel A100, Lenzing Lyocell, Newcell, Alceru, Orcel, Cocell, Visage etc. Lyocell fibres are used in the production of dresses, coats, sweaters, sportswear, underwear, bedspreads, curtains, hygiene products, umbrellas, tent fabric, carpets, mattress fillings, coffee filters, filters, cleaning papers, paper pulp etc.(Cebeci, 2013).

***Seacell fibre***

A new fibre has been developed as a textile raw material. The products made from these fibres are transferred to the body through the skin and also have antifungal and antimicrobial properties. Seaweed contains carbohydrates, vitamins and proteins, as well as the minerals found in seawater, which are absorbed and retained in seaweed products. They have long been used in the cosmetics industry, particularly in skin protection and cleansing products. The fibre obtained by treating Lyocell fibre with seaweed is known as Seacell fibre and is available in cellulose + seaweed and cellulose + seaweed + seaweed + silver ions (Figure 2). Therefore, Seacell fibre, derived from beech trees, is noted for its durability, softness, and excellent moisture transfer properties, making it a valuable option in sustainable fashion and textile design.

*Figure 2. Seacell fibre (Cebeci, 2013)*

***Modal fibre***

It is strong, soft and shiny. This fibre is made from beech wood. The main characteristic of this fibre is that it is light and resistant to wear. With good moisture transfer properties, it absorbs moisture faster than cotton and dries quickly. It remains bright and soft even after many washes (Cebeci, 2013).
These fibers are the most prominent fibers among regenerated cellulose fibers. It is expected that the production quantities of these fibers will increase and become widespread in the near future.

## CONCLUSION

The move towards sustainable fibres in the textile industry is a significant step towards reducing environmental impact. By prioritising green production methods and adopting sustainable practices, companies can contribute to a more sustainable future while meeting consumer demand for environmentally friendly products. The properties of sustainable fibres, combined with effective production strategies, highlight the potential for a more responsible textile industry. In conclusion, the exploration of sustainable fibres in the textile industry highlights the importance of environmentally friendly production methods and the distinct characteristics of different fibres such as various rayon fibers; Lenzing Ecovero, Lyocell and Seacell etc. It is expected that the importance and usage amounts of these regenerated rayon cellulosic fibers will increase in the near future due to their contribution to sustainable textile production and their good textile performance properties. The contrast between fast fashion and slow fashion underlines the need for a shift towards higher quality and more sustainable products. As the industry moves forward, it is crucial for companies to adopt environmentally friendly practices and develop strategies in line with consumer demands for sustainability. This transition not only supports environmental goals, but also promotes a more responsible and conscious approach to fashion and textile production.

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# DECONSTRUCTING LOGOMANIA: A CASE STUDY OF MAVI

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**ABSTRACT**

The contemporary fashion landscape has witnessed a resurgence of the Logomania trend, wherein prominent logo displays function as both fashion statements and brand identity reinforcements. This study investigates how Mavi, a globally recognized lifestyle brand, has strategically employed this trend to develop innovative product categories aligned with contemporary consumer preferences. Focusing on key design product groups such as the MV-91, Mini Branding Jersey, and the MIAV Jersey, the research examines the integration of bold logo designs with sustainable materials like BCI cotton to enhance both aesthetic appeal and functional value. Employing a case study approach, this research provides an in-depth exploration of Mavi's design initiatives within the context of the Logomania trend. This method allows for a nuanced understanding of contemporary phenomena within real-world settings. Data collection involved participant observation within Mavi's design and category teams, focusing on the development and execution of Logomania-inspired products. Additionally, document analysis was conducted on design briefs, marketing materials, and internal reports concerning consumer feedback and sales performance. Qualitative data analysis employed coding techniques to categorize information into themes related to design processes, brand reinforcement, and consumer reception. This study concludes that Mavi's strategic approach to Logomania not only reinforces its brand image but also provides a competitive advantage within the global fashion market. These findings highlight the dynamic interplay between consumer culture and branding strategies within the luxury fashion industry.

**Key words**: Logomania, Mavi, logo design, sustainable fashion, menswear

## INTRODUCTION

Logos and symbols are the visual language of brands, conveying identity and values in a rapidly moving world. These elements transcend mere design, becoming embedded in our daily lives as markers of quality, aspiration, and even personal expression. On a global scale, visual identity elements like logos are meticulously crafted to be both memorable and enduring, ensuring brand recognition across diverse markets. This is particularly crucial in the fashion industry, where trends shift rapidly, and brand loyalty is fiercely contested (Kaya, 2020).

Within the apparel sector, logos hold a unique power. They act as shorthand for a brand's story, heritage, and perceived quality. A well-designed logo can communicate volumes about a brand's target audience and its position within the market. Historically, prominent logo placement on garments became synonymous with luxury and exclusivity. However, consumer preferences are dynamic. While some demographics continue to associate logos with prestige, others, particularly younger generations, are drawn to more subtle branding or even logo-free clothing (Fibre2Fashion, 2024). This shift highlights the need for brands to strategically navigate the evolving landscape of logo usage.

WGSN, a globally recognized trend forecasting agency, plays a vital role in deciphering these trends. Their expertise lies in identifying and analyzing shifts in consumer behavior, providing valuable insights to businesses across various sectors (DuBreuil & Lu, 2020; Jackson, 2007; Rousso & Ostroff, 2018). WGSN's Spring-Summer 2023 trend report, aptly titled "Logomania," underscores the resurgence of bold logo usage, particularly in menswear and streetwear (WGSN, 2024). Although the Logomania trend is currently in vogue, its origins trace back to the 1980s. During that decade, with the rising interest in luxury fashion, the trend of heavy logo usage began. By the early 2000s, this trend had been formally christened "Logomania." The impact of Logomania is evident in the collections of major fashion houses such as Louis Vuitton, Burberry, Fendi, Celine, Balmain, and Versace across different years (Vouge, 2021). Exaggerated scales and stitching placements create an eye-catching aesthetic, particularly appealing to streetwear and youth product groups. This trend, known as "Badged Up," offers significant opportunities for using surplus brand labels and embellishments (Chow, 2022). As Figure 1 illustrates, brands like Kenzo are at the forefront of this trend, showcasing innovative and eye-catching logo placements.

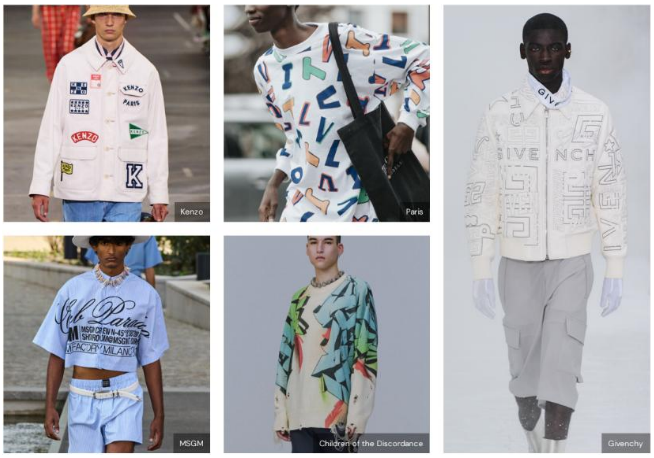


*Figure 1: Logomania Trend, Spring-Summer 2023 (WGSN, 2023)*

This study seeks to investigate how Mavi has incorporated the Logomania trend to meet both aesthetic and environmental objectives. Main focus is given to the innovative designs, in line with the Spring-Summer 2023 WGSN "Logomania" trend. The research specifically aims to analyze how bold logo placements and exaggerated scales, particularly in the streetwear segment, is integrated in various product groups to influence consumer behavior and strengthen brand identity. In doing so, it explores how Mavi strategically embraced the Logomania trend, combining bold logo designs with sustainable materials such as Better Cotton Initiative (BCI) cotton to respond to contemporary consumer demands for both style and sustainability.

**EXPERIMENTAL PART**

This study adopts a case study approach to gain an in-depth understanding of how Mavi integrates the Logomania trend with sustainability practices. Case studies are particularly well-suited for examining complex phenomena within their real-world context, providing rich and detailed insights (Hancock & Algozzine, 2006). Unlike experimental studies that focus on comparisons and hypothesis testing, case studies aim to explore, describe, and categorize phenomena to develop a deeper understanding of the subject matter (Subaşı & Okumuş, 2017).

The case study focuses on Mavi's key product categories, including the MV-91, Mini Branding Jersey, and MIAV Jersey, examining how the brand incorporates bold logos into these product designs while utilizing BCI cotton to meet consumer demand for eco-friendly fashion. Data collection involved participant observation within Mavi's design and category teams to observe the development process of Logomania-inspired products. Additionally, document analysis was conducted on design briefs, marketing materials, and internal reports related to consumer feedback and sales performance. These data sources provide a comprehensive understanding of how logo placement and sustainability considerations intersect in Mavi's product development and branding strategies.

## RESULTS AND DISCUSSION

This study examined how Mavi incorporates the Logomania trend into its product design while adhering to sustainable practices. The analysis focused on specific product lines to understand how Mavi balances aesthetic appeal with ethical and environmental considerations. The findings suggest that Mavi successfully integrates bold logo designs with sustainable materials in product lines such as the MV-91, Mini Branding Jersey, and MIAV Jersey. This approach adds value to the products by appealing to contemporary consumers who increasingly prioritize eco-conscious fashion choices.

### MV-91 Product Group

Designed as a luxury-themed "basic" package for young adults, the MV-91 product group targets the Spring-Summer 2024 season. This product group expand upon the previous season's offerings with the addition of new items. Two popular T-shirt models from the previous season are reintroduced, while new designs broaden the product range. A new MV-91 graphic, created using a combination of embroidery techniques, is introduced in this product group. Satin stitch, chain stitch, Chinese needlework, and EVA padding embroidery techniques create a complex and visually engaging design.

Oversized fits are prevalent throughout the product designs, with a cropped T-shirt introduced this season. Additionally, two new models crafted from jacquard mesh fabric—a top and a pair of shorts—are included. The MV-91 product group comprises a total of eight models, primarily in black and white, maintaining a minimalist yet bold aesthetic. Figure 2 will present sketches of the designs included in this product group.


*Figure 2: SS24 MV-91 product group; oversize, jacquard mesh shorts and t-shirt set, cropped t-shirt*

### Mini Branding Product Group

Targeting young adults who prioritize comfort, the Mini Branding product group is set to launch in the SS24 season. These designs introduce a new brand identity element by incorporating silicone-based logos as an alternative to Mavi's traditional blue logo. Demonstrating a commitment to both environmental sustainability and quality, the Mini Branding product group utilizes BCI-certified cotton. The designs offer a variety of styles and colors within a mini product group, including two T-shirts, one crewneck sweatshirt, and one hooded sweatshirt. All designs aim to balance comfort and style, appealing to a wide consumer base with a color palette that features modern, dynamic shades such as White, Snow Melange, Tigerlily, Alaskan Blue, and Bougainvillea. Figure 3 provides sketches of the product group.

*Figure 3: SS24 Mini branding sketches*

BCI cotton is produced using methods that strive to minimize negative environmental impacts while simultaneously improving the livelihoods and well-being of farming communities. Recognized as a global standard for more sustainable cotton production, the Better Cotton Initiative aims to reduce the environmental and social impacts associated with conventional cotton production, ultimately making the industry more sustainable and secure for the future. BCI encourages participation from stakeholders across the entire cotton supply chain, from producers to retailers, facilitating collaboration to achieve shared environmental and social responsibility goals (Orta, 2024).

BCI has played a significant role in the global growth of sustainable cotton production. Recent years have witnessed a notable increase in the number of brands opting for BCI-compliant cotton. As of 2016, BCI-compliant cotton accounted for 16% of global cotton production, cultivated in 20 countries across five continents. By promoting sustainable and environmentally responsible approaches to cotton production, BCI has emerged as a leader in driving positive change within the industry, aligning with the increasing consumer preference for healthy and environmentally friendly options (Sevinç, 2022).

**BTS Logo Product Group**

Designed for young adults, the BTS Mavi Logo product group introduces several innovations for the SS24 season. The product group features a new color palette, including Maritime Blue, Nebulas Blue, Laurel Wreath, Walnut, Amazon, Seal Brown, Mars Red, and Cilantro. Offering variety in graphic design, the product group includes different logo sizes and both "loose fit" and "regular fit" styles.

A standout piece in the BTS Logo group is a pair of sweatpants featuring a small BTS logo, which has emerged as a bestseller. The group also includes two T-shirts with varying logo sizes, a crewneck sweatshirt, a hoodie, and the aforementioned sweatpants. These items provide aesthetic diversity through varied graphics, color options, and fits, catering to the preferences of younger consumers. Figure 4 showcases sketches of the designs for this product group.


*Figure 4: SS24 Casual Young BTS Logo Jersey Capsule*

The Spring 2024 products incorporate brush effects and 3D text into its logo designs, creating eye-catching graphics. Spray effects further enhance the youthful and dynamic aesthetic. Advanced molding techniques amplify the impact of the spray effects, drawing attention to details beyond the classic Mavi logo and seal (Figure 5).


*Figure 5: Logo details*

For the Mavi Seal logos, towel embroidery patches in various colors lend a unique character to the graphics. The embroidery highlights the intricate details of the logos, contributing to the youthful and dynamic look. The integration of diverse font sizes and placements with other design elements creates a more dynamic and visually appealing aesthetic (Figure 6).


*Figure 6: SS24 Logo Tee Capsule*

In line with Mavi's commitment to sustainable design, the BTS Logo product group incorporates organic cotton in some models. The addition of 4-5 new colors, including Celestial Blue, Pearl Blue, Raven, Black, and White, to the existing graphic logo models further enriches the designs. This approach effectively merges environmental responsibility with aesthetic appeal, resulting in a product group that is both sustainable and attractive. Also, building on its success in the previous season, the MIAV product group returns for the current season with new innovations (Figure 7).


*Figure 7: MIAV Product Group Sketches and Applications*

**CONCLUSIONS**

This study demonstrates how Mavi effectively leverages the Logomania trend to develop innovative product categories that resonate with modern consumer preferences. By combining bold logo designs with sustainable materials like BCI cotton, Mavi creates products that are both aesthetically appealing and aligned with the growing consumer demand for eco-conscious fashion. The strategic placement of logos, particularly within the MV-91, Mini Branding Jersey, and MIAV Jersey pproduct groups, reinforces brand identity while showcasing how sustainability can be seamlessly integrated into desirable fashion-forward designs.

Mavi's success stems not only from embracing a popular trend but also from adapting it to reflect a commitment to responsible production. The use of BCI cotton, organic materials, and environmentally sound processes highlights Mavi's proactive approach to meeting consumer expectations for ethical and sustainable practices within the fashion industry. This commitment, evident in the brand's diverse product range and innovative use of materials like silicone-based logos, positions Mavi as a leader in sustainable fashion, appealing to both style-conscious and environmentally aware consumers.

To further solidify its competitive advantage, Mavi could explore expanding its use of sustainable technologies, such as advanced recycling methods or renewable energy sources in its manufacturing processes. Additionally, enhancing consumer education about the environmental benefits of BCI cotton and other sustainable materials could strengthen Mavi's image as a pioneer in responsible fashion. Such efforts would likely resonate with the increasingly eco-conscious consumer base, fostering brand loyalty and driving market success.

Looking ahead, Mavi's strategic approach to Logomania, with its emphasis on innovation, sustainability, and consumer engagement, positions the brand for continued growth. The findings from this study suggest that Mavi's model -successfully combining bold, iconic logos with responsible materials and production methods- could inspire other fashion brands seeking to capitalize on global trends while integrating sustainability into their core practices.

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# THE INFLUENCE OF NEW ROMANTICS' FASHION AND 80'S MUSIC ON THE CREATION OF A SET OF FASHION ILLUSTRATIONS FOR THE 21ST CENTURY

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## ABSTRACT

The bond that the music and fashion industry share, especially since the second half of the 20th century, is undeniably an unbreakable one. No matter if it was something recorded in newspapers or magazines, seen on television or live, a musician's fashion choice was something fans have paid close attention to and imitated in the desire to feel closer to their idols. Music proved to be an outlet for self-expression, transforming performances into possible cultural milestones and trends we know of today. During the turbulent times of the 20th century which had changed the world at a never before seen pace, many art forms have been affected and influenced by what was going on in every part of the world, which resulted in pop culture finding its way and cementing its place in the lives of everyday people, as either a form of escapism or self-fulfilment. Fashion, of course, followed suit, and artists such as David Bowie, Prince and Annie Lennox have led a revolution both on the stage and on the screen with their era-defining music as well as their fashion choices that left everyone looking dazzled and impressed, with fans eagerly wanting more.

**Key words**: pop music, fashion illustrations, Vivienne Westwood, rococo, influence

## INTRODUCTION

Ever since Elvis Presley put on eyeliner and donned a sequin jumpsuit, musicians have been slowly but surely changing their approach to dressing on stage. Presley is considered an unquestionable pioneer when it comes to separating classic men's clothing. Wearing the gold suit on the cover of "50,000,000 Elvis Fans Can't Be Wrong," he was, as Tommy Hilfiger put it, "the first white boy to really turn up the bling." Presley was among the first to move away from the "masculine" rockabilly singer image to floral designs and pink jumpsuits covered in rhinestones, like the one made for him by Nudie Cohn, and even popularized Hawaiian style with his red hibiscus-embellished shirt in the movie "Blue Hawaii ", which Prada, Dior and Saint Laurent soon adopted. With his risqué, colourful, skin-tight clothing, he paved the way for artists like David Bowie and Mick Jagger to wear their own more extreme iterations of those combinations on stage. Among those whom Presley inspired even after his death was Tupac, who gave his suits a touch of gold and walked among models covered in gold at the Versace fashion show in the 90s. Hendrix, The Beatles, David Bowie, Queen and many others continued that path of revolutionizing the fashion scene through their music performances and fashion choices, playing with androgynous styles as a form of self-expression and influencing many fans and designers alike, changing the pop culture at a rapid pace. All of which can be seen in the special fashion subcultures that came to be in the 80s, one of which is the *New Romantics* subculture.

## PIRATES OF THE WESTWOOD FASHION SHOWS

By the time the 80s rolled in, with it came a plethora of new and exciting music genres and fashion styles into the mainstream, Vivienne Westwood was already a household name in alternative and punk subcultures of Great Britain. Designing for common folk as well as the greats such as The Sex Pistols, she and her then-partner McLaren have cemented their place in the fashion world. "My job has always been to confront the establishment to try and find out where freedom lies […] I don't really want to talk that much about fashion. It's only interesting to me if it's subversive," said Vivienne in 1981, the same year her debut to the haute couture world happened with the Autumn/Winter collection simply titled *Pirate*. (Cody, 2016) By the start of the 80s, punk had become a mainstream worldwide hit, losing its former status of a fully anti-establishment music genre, which prompted Westwood to search elsewhere for inspiration of unconventional beauty that doesn't fit the aesthetics of what's considered modern. Dandy, colourful and rich with historical inspirations, the *Pirate* collection was filled with sashes, military frock coats, oversized frilly shirts and loose trousers, all topped with pirate hats and colourful avant-garde make-up looks, all which showed Westwood’s deep love and appreciation of historical British clothing from the 17th to the 19th century, something that will stay a part of her brand’s iconic imagery moving forward. Like many of her former creations, this collection inspired British musicians and club goers alike, popularising a look that was becoming quite influential on its own at the time – the *New Romantic*. (Victoria & Albert Museum) The New Romantic movement had quite a bit of influence on the collection as well as vice versa, the post-punk style firstly known as “peacock punk”, which is a nod to the *Peacock Revolution* that happened during the 60s, was becoming quite the rage in late 70s street fashion and in the London’s Blitz nightclub, where the participants of the subculture would combine exotic silhouettes that ruled the rock’n’roll scene through the likes of Jimmy Hendrix and Mick Jagger, mixed together with the outrageousness of punk as well as alien hairstyles and make-up, many noting the connection between new romantics and the styles of David Bowie. (Cody, 2016) For *Harpers & Queen* magazine in 1983, Westwood stated that her main philosophy with garments is that they should make one feel “grand and strong”, giving awareness to the wearers body through their clothes. (Victoria & Albert Museum Collections, 2003)

## THE DANDY NEW ROMANTICS: POST-PUNK FASHION AND MUSIC THAT DAZZLED THE 80S

After the likes of Bowie paved the way in androgynous fashion presentation in the music and fashion scene, there was a rise in demand for sartorial extravagance among youth subcultures of the West. With a romantic nostalgia, the *New Romantics* became the new *New Wave* in British youth cultures that were closely connected to the Blitz club, as well as all around the UK, trading the angry and outrageous aesthetics of punk for a more floral, frilly and techno-futuristic as a form of being anti-establishment in the Thatcher era of the early 1980s, while combining history with modernity. (Worley, 2024) it was a mix of eccentric and flamboyant looks already solidified by glam rock stars of the former decade, with a touch of heavily romanticized silhouettes of the late 18th to early 19th century, a little bit of rococo hedonism with the visual styles of the neo-classical era, all combining into a an anti-fashion statement from the disillusioned group of young people that had their own take on the fast-shifting socio-political environment they have found themselves in. Much like the aristocratic fashion from the rococo period, the *New Romantics*, with icons such as David Bowie, Marc Bolan and Roxy Music to name a few, strived for glamour and grandeur, while being adorned with lace, Basque waists, countless accessories and avant-garde make-up looks and statement collars, bigger was always better. (McEllin, 2023) “I’m sick of this new Puritanism there’s been in England since ’76,” Adam Ant, one of the main representatives of the subculture’s music scene, stated in an interview with Michael Watts, “I think the kids, too, are sick of being thought of as ‘We’re all in the gutter together,’ dressing only in black and grey, being the Blank Generation [...] I like a bit of colour, a bit of flash, a bit of honour, a bit of dash.” (Borrelli-Persson, 2021) Adam and the Ants were regularly seen in the latest Westwood had to offer in terms of garments, looking like they themselves participated in her *Pirate* (A/W '81) or *Buffalo Girls/Nostalgia of Mud* (A/W '82) runways – “wild” geometrical make-up styles, hussar jackets akin to the ones Hendrix regularly wore, pirate hats and synthy post-punk music, the band became a darling amongst both Blitz regulars as well as fans who rushed to imitate such eccentric looks. It was a welcoming style regardless of the wearer’s gender, a statement of softness and fluidity that paved its way back into mainstream fashion. Westwood herself said “The ’80s will be a technological age for which we need to equip ourselves with a feeling of human warmth from past ages — of culture taken from the time of pirates and Louis XIV,” describing the *New Romantic* sensibilities of the time.

(Borrelli-Persson, 2021) It was an all-encompassing trend, from the aforementioned Adam and the Ants that had a swash-buckling flare
to them, to the more sombre and mature but ever so avant-garde nature of the pop band Japan, as well as one of the biggest most flamboyant acts in the history of 20th century rock music with Prince, and the touch of theatrics seen with mega-acts such as Annie Lennox, fans were eager to imitate, and designers were eager to create. (Worley, 2024) Looking at the styles of the so-called "Blitz-Kids", both Stan Hawkins and Michael Bracewell argue that the dandyism present in their visual imagery is a way to "feign masculinity" in their performances, unrelated to ones gender, while leaning heavily into the effeminate as a way to combat gender expectations, something that revolutionized men's dress. On the other side, Caroline Evand and Minna Thornton argue that the same femininity available to women has been appropriated by men to explore the "multiplicity of self", shifting men's expression from the simple holder of masculine observation to an object to be observed by others, changing societal relationship in such underground cultures and allowing a more masculine role for women. Identity expression has with such cultures shifted from a gender androgyny being entirely connected to queerness to a rather democratized approach to who and of which background can wear certain garments, and what that means for gender performance. (Worley, 2024)
Talking about the romanticism and androgyny that came with it all, it's impossible not to mention Prince as one of the leading forces in the US music and fashion scene. Going against gender-assigned aesthetics, invoking themes of sexuality and fluidity in his music and visuals, he amped-up the futuristic *New Romantics* style to new heights in the US, both through his music videos and tours. Fashion as a form of reinterpreting the themes of his lyrics, bold colours such as purple, which became his trademark colour, velvety double-breasted form-fitting and cropped suits, heeled boots, ruffles, lace and jewellery were all an undeniable part of his image. His goal was to wear something extravagant, something he has many times stated he wears for the simplest reasons – because he looks good in it and knows that women find it attractive. All of his outfits were custom made for his tours by his trusted ateliers – it was an entirely unique and fully Prince look that he curated himself. This approach to breaking gender stereotypes, masculine identity through effeminate clothing in the music industry has inspired artists such as Harry Styles and Frank Ocean, who has stated that due to Prince's liberating fashion choices he himself feels more validated in his own gender and identity expressions. (Schmidt-Rees, 2019) His influence became noticeable on runway shows as well, with Dolce & Gabbana, Gucci and Roberto Cavalli honouring his style in their own ways, as well as Christophe Decarnin capturing his extravagant style for his A/W 2010 collection. (Yotka, 2016) Similarly to Prince, Duran Duran played a big part in the *New Romantics* look – padded oversized shoulders and radiant and pastel suits, prints that adorned their garments and lavish scarves that had a nonchalant flare to them, all paired with slim-fit pants that proved to be quite popular in 80s fashion, they never shied away from a flamboyant look. Lace-ups, lavish bows and hairstyles, as well as hussar/military jackets, they evoked the aesthetics similar to Adam and the Ants, while also putting on biker leather jackets and combat boots to juxtapose the classic *New Romantics* look with a little touch of rock'n'roll. Continuing the path made by Bowie, they lead the *New Wave* to exciting directions. (Cantarini, 2021)

## CREATING THE FASHION ILLUSTRATIONS

After a brief look at the history and the main protagonists of the *New Romantics* movement in the music and fashion industry, the main goal is to create fashion illustrations that are inspired by this research. The colours of the collection are pastel and light, giving a rather youthful note to the silhouettes that are a mix of modern and historical. The silhouettes themselves draw inspiration from rococo menswear of France and Britain from the 18th century, with the touch of unconventionality inspired by Vivienne Westwood's aforementioned *Pirates* collection. Floral motifs and padded shoulders are a nod to 80s fashion and pop culture, with the 1984 movie "Amadeus" playing as big of a role on the designs as Prince's stage costumes have. Flamboyancy and romantic nostalgia with a touch of futurism is the main feeling for these illustrations strives to invoke in the viewer. The fashion illustrations themselves are inspired by the works of the fashion illustrator Tony Viramontes, who has often combined music, photography and fashion to create bold looks. The mood board shown below serves as inspiration for featured illustrations and shows the main components of the research.


*Figure 1: Mood board*

*Figure 2: Selected illustrations; original designs and illustrations by Kristina Vinčar*

In a deeper sense, this collection celebrates nonconformity that comes with fashion subcultures of the 80s. As it was a decade of economical prosperity in the West, the fashion was opulent and the people decadent. Art was in a constant state of movement, as new urban art-movements such as graffiti pop art and neo-expressionism have shaken the scene to its core, and so have those same artists challenged how we approach art and how that art should be consumed with its conections to fashion. All which refflected itself on collaborations such as the one between Kieth Haring and Vivienne Westwood for the *Witches* collection (Autumn/Winter 1983), both socially concious artists in their own right, bold and brash, but also connecting two different audiences to participate in such an event.

*Figure 3: Selected illustrations; original designs and illustrations by Kristina Vinčar*

*Figure 4: Selected works, original designs and illustrations by Kristina Vinčar*

**CONCLUSION**

In the twentieth century, which was marked by numerous and radical changes, those who threw off the shackles of traditional appearance and purity in their public performances were as much vanguards and torchbearers as they were followers, a reflection of the multitude that was changing with them. Such audacity paid off, not only through their unquestionable popularity, but also emancipated the individual from the rules of expression according to the dictates of religion and the state, thus bringing whole generations closer to the ideal of equality and equity. Fashion illustrations themselves as well have played an important part in fashion that connects it to music history and pop culture. While following trends and even shaping fashion itself, greats such as Viramontes have worked countless times with musicians to help design their album covers, such as his work with Janet Jackson on her 1986 album "Control". Even more so, *New Romantics* themselves, as big fans of fashion and what it can do, have showed appreciation towards fashion illustrations, with Duran Duran having illustrator Patrick Nigel design the artwork for their 1982 album "Rio". Fashion and music resonate with people, give them a way to understand things that seem illogical to them and accept them with their hearts, reminding us all that science can give explanations, but only art can intervene and change the world for the better.

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# RECENT APPROACHES IN COTTON PRODUCTION

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**ABSTRACT**

This paper compares recent sustainable cotton approaches in the textile industry with their respective life cycle assessment (LCA) values. When the concept of sustainability is approached via its environmental, social, and economic dimensions, phrases like "Green Textiles" and "Organic Textiles" emerge in today's setting. It is said that typical cotton production causes environmental problems due to high water and chemical usage, whereas organic cotton and other sustainable alternatives aim to reduce these consequences. This paper revealed that recent sustainable cotton production approaches have much fewer negative environmental effects than standard cotton production.

**Key words**: Cotton, cotton production, recent approaches, organic cotton

## INTRODUCTION

The concept of sustainability was first introduced into the literature in 1972 with the publication of the seminal report by the Club of Rome. The report demonstrated that the depletion of natural resources, contamination of the environment, increase in food consumption and the continuation of industrialisation in this manner would ultimately result in the unsustainable growth of the global economy. Consequently, the concept of sustainability was addressed at the World Commission in 1987. In consequence, the concept of sustainability is concerned with three principal areas: the environment, society and the economy. Sustainable development can be defined as the ability to meet the needs of current generations without affecting the production resources of future generations (Mangır, 2016; www-1; www-2; Eser et al., 2016; Cebeci, 2013; Yücel & Tiber, 2018).

At the World Summit in Brazil in 1992, all countries accepted and developed the concept of sustainability. Accordingly, sustainable development is divided into four basic dimensions that are integrated with each other (Mangır, 2016). These are:

- Economic development (and equitable distribution of wealth)
- Social development (and ensuring equality and social mobility)
- Protection of the environment and natural resources
- Technological transformation (which includes the reduction of environmental pollution through technological transformation) (Mangır, 2016; Yücel and Tibet, 2018)

The term "sustainability" has given rise to a number of related concepts, including "green textiles," "organic textiles," "ecological textiles," "ecological design," "design for the environment," "design for sustainability," and "life cycle assessment (LCA)." These concepts have emerged as key areas of focus within the larger field of sustainability studies (İşmal, Yıldırım, 2012).

### LCA for Sustainability

A Life Cycle Analysis (LCA) is an approach that begins with the raw material utilized in the production of a given product or service and proceeds to encompass the entirety of the production process, the

subsequent shipment of the product, its utilization by the consumer, and ultimately, its disposal as waste at the conclusion of its useful life. The objective is to identify, report and manage environmental impacts at all stages. The evaluation of environmental impacts is conducted according to a set of defined categories, including those concerning impact on climate change, ozone depletion, eutrophication, acidification, and toxic emissions. It is essential to consider the environmental impacts of the materials and technologies employed in all activities on a life cycle basis (Özkan et al., 2018; İşmal and Yıldırım, 2012).
A life cycle analysis of jeans reveals that the production of a single pair results in the emission of 33.2 kg of carbon dioxide. The production of these jeans requires the consumption of 3,480 litres of water and 400 mega joules of energy. This consumption equates to 78 miles of travel, 53 showers, and the viewing of a plasma TV for 318 hours (Cebeci, 2013). Environmental issues are typically associated with the utilization of energy, water and chemicals, direct $CO_2$ emissions and solid waste. The intensity of an environmental footprint can vary depending on the stage of the textile or clothing product life cycle (Table 1).

*Table 1. Major environmental issues associated with the life cycle stages of products Environmental Issues (Koszewska,2018)*

| Environmental Issues | The most effective stages in the product life cycle |
|---|---|
| Energy Consumption | Man-made fibre production, yarn production, finishing processes, washing and drying of laundry during use |
| Water and Chemical Consumption | Fibre growth, wet pretreatment, dyeing, finishing and washing |
| Solid Waste | Disposal of end-of-life products, textile/clothing manufacturing |
| Direct $CO_2$ Emission | Transport within globally distributed supply chains |

The ecological factor is also influenced by the colors of the fabrics, the washing and dry-cleaning processes, and the maintenance processes, such as ironing. A study conducted in 1995 examined the environmental impact of two T-shirts produced using organic cotton and conventional cotton, respectively, and evaluated the costs associated with each stage of their life cycle. The study revealed a significant cost difference, with the organic cotton T-shirt exhibiting a cost advantage of up to 70-80% compared to the conventional cotton alternative. In a separate study, it was demonstrated that an item of clothing remains in a wardrobe for an average of three to five years, with the garment being worn 44 times during this period and washed every two to three days. It has been observed that garments that are washed frequently have a markedly high environmental impact. Consequently, in order to develop a product with a minimal environmental impact, it is essential to select the most suitable textile materials, optimize colours and minimize the number of washes throughout the product's lifetime. Prior to the pandemic, designers have investigated how textiles can be used to prevent garments from being worn for a very short time and washed too often at a high temperature (İşmal and Yıldırım, 2012).

### Various Approaches For Sustainable Cotton Production and Their Comparison with LCA

The cotton plant has a complex structure comprising a stem, root, leaf, flower and seed. The cultivation of cotton requires the use of significant quantities of chemical agents, including pesticides, fungicides, and insecticides (Cebeci, 2013). Cotton is one of the most intensively utilized fibres in the textile production industry. However, the chemicals used in cotton production and the excessive consumption of water have resulted in an increase in ecological problems. A substantial proportion of the pesticides employed globally are utilized in the cultivation of cotton. Consequently, the demand for 'organic cotton', which is proposed as an alternative to conventional cotton, is on the rise both globally and domestically (Eser et al., 2016; Çolakoğlu, 2018; www-3).

A number of terms are employed to describe approaches aimed at facilitating the transition from conventionally cultivated cotton to more sustainable techniques. One such term is "preferred cotton." It is of the greatest importance to facilitate a transition from programs that have a negative impact on the environment to those that establish, reinforce and implement regenerative practices. The Textile Exchange defines a preferred fibre or material as one that results in superior environmental and/or social sustainability outcomes and impacts in comparison to conventional production (www-3).

The recognition or acquisition of a preferred product may be achieved through a variety of means, including, but not limited to, the following:

- The fibre or material has been developed in accordance with formalized multi-stakeholder sustainability criteria.
- The fibre or material has been awarded a recognized industry standard confirming its preferred status.
- A robust chain of custody system is in place to track or trace the fibre or material through the supply chain and back to its source.
- The fibre or material has undergone objective testing or verification to demonstrate superior sustainability attributes, such as a peer-reviewed life cycle assessment.
- The fibre or material has the potential for high circularity (www-3).

The market share of preferred virgin cotton exhibited a notable increase, rising from five per cent of total cotton production in 2012/13 to 22 per cent in 2017/18. The figures for preferred cotton presented here include those for ABRAPA, BASF e3, the Better Cotton Initiative (BCI), Cleaner Cotton, Cotton Made in Africa (CmiA), Fairtrade, Fairtrade Organic, Farm to Market, ISCC, myBMP, Organic, REEL Cotton, Regenerative Cotton and Transitional Cotton (www-3). Further detailed information on select preferred cotton production systems and their associated life cycle analysis (LCA) data is provided in the following Table 2 (www-3).

*Table 2. A comparison of the life cycle analyses of conventional cotton and sustainable cotton production systems (www-3)*

| **Life cycle values** | **Traditional cotton** | **Cotton made in Africa (CMIA)** | **Global Organic Textile Standarad (GOTS)** | **MYBMP** | **ORGANIC CONTENT STANDARD (OCS)** | **ORGANIC COTTON** |
|---|---|---|---|---|---|---|
| **Water Consumption ($m^3$ / 1000kg fibre*) or best practices used to conserve water** | 1,559 (LCA) | 1 (~100% reduction - LCA) | 182 (88% reduction - LCA) | 0.5 $m^3$/MT Irrigation Water Use Efficiency (DPI, 2019) 67 criteria related to water management | 182 (88% reduction - LCA) | 182 (88% reduction - LCA) |
| **Primary Energy Demand MJ / 1000 kg fibre*** | 13,720 (LCA) | - | 5,800 (58% reduction - LCA) | 4000Mj/1000kg mohair (on-farm only) + 17 criteria addressing energy efficiency in myBMP. | 5,800 (58% reduction - LCA) | 5,800 (58% reduction - LCA) |
| **Global Warming (kg $CO_2$-eq/1000kg fibre*)** | 1,326 (LCA) | 1.037 (22% reduction - LCA) | 978 (26% reduction - LCA) | - | 978 (26% reduction - LCA) | 978 (26% reduction - LCA) |
| **Eutrophication (kg phosphate-equivalent / 1000 kg fibre*)** | 7.8 (LCA) | 20.4 (161% increase - LCA) | 2.8 (64 % reduction - LCA) | - | 2.8 (64 % reduction - LCA) | 2.8 (64 % reduction - LCA) |

A comparison of the environmental impacts of traditional and organic cotton production systems can be made on the basis of their life cycle analyses (LCA). The consumption of water is a significant factor to consider in the context of agricultural production. The production of organic cotton results in an 88% reduction in water consumption per kilogram in comparison to the production of traditional cotton. This indicates a significantly lower environmental impact in terms of water usage for organic cotton.

*Eutrophication:* Furthermore, organic cotton demonstrates a 64% reduction in eutrophication (as measured in phosphate equivalents) in comparison to traditional cotton. This indicates that organic cotton production is less detrimental to aquatic ecosystems (www-3).

*Global Warming:* A 26% reduction in global warming potential is associated with organic cotton in comparison to traditional cotton. This emphasizes the reduced carbon footprint associated with organic cotton production.

*Market Share of Sustainable Cotton:* As of 2019, 22% of the world's cotton was reported to be produced in a more sustainable manner, with nearly 6 million metric tons of the 26 million metric tons of global cotton production classified as preferred cotton. This suggests a growing tendency towards more sustainable practices in cotton production.

*Overall Environmental Impact:* The prevailing methods of cultivating cotton are identified as the most environmentally detrimental, with a particular focus on the consumption of water, the emission of carbon, and the utilization of pesticides. In contrast, organic cotton production methods are recognized as having a significantly lower environmental impact (www-3).

## CONCLUSION

A comprehensive analysis of cotton and preferred cotton values reveals that conventional cotton is the most detrimental production method in terms of its impact on the environment. This is evidenced by its significantly higher water consumption, carbon emissions, and pesticide use compared to other methods. It is evident that the method which causes the least damage to the natural environment is organic cotton. It is imperative that efforts be made to increase the production of preferred cotton in order to facilitate the production of a more sustainable variety of cotton. In 2019, it was reported that 22% of global cotton production was more sustainable, with 6 million tons of this production classified as preferred cotton. This situation serves to highlight the necessity for the adoption of more sustainable methods of cotton production.

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# PRODUCTION OF ENVIRONMENTALLY FRIENDLY AUTOMOTIVE SEAT FABRICS AND INVESTIGATION ACCORDING TO AUTOMOTIVE STANDARDS

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**ABSTRACT**

EU regulations on sustainability (Green Deal and Circular Economy Action Plan) require the development and use of recycled, bio-based or biodegradable materials on vehicles. These regulations aim to reduce non-recyclable, unsustainable and non-renewable material waste in Europe up to 50% by 2030. Therefore, automotive producers and sub-suppliers tend to become of searching for new sustainable and environmentally friendly materials instead of conventional fossil-based materials. The automotive seat fabrics include three different layers: the aesthetic layer consisting of woven or knitted fabric produced with polyethylene terephthalate (PET) yarns, the intermediate layer consisting of polyurethane (PU) lamination foam, and the bottom layer consisting of the lining fabric produced with PET yarns. In this study, a comparable seat fabric was produced using PET yarn with added biodegradability feature for the aesthetic layer, bio-based PU foam for the lamination layer, and recycled PET yarn for the lining layer under the same conditions, structures which is already in serial production. According to international standards, mechanical tests have been performed to compare the properties of elongation at break, tenacity, and shrinkage behaviors of biodegradable and fossil-based PET yarns. The mechanical properties of produced fabrics such as abrasion, snagging, elongation, and light fastness were investigated regarding to Stellantis norms. As a result of this study, It was observed that sustainable and renewable yarn and seat fabric have sufficient mechanical performance for use in the automotive sector instead of fossil-based yarn and fabric.

**Keywords**: automotive seat fabric, sustainability, mechanical property, automotive standards

## INTRODUCTION

Automotive textiles consisting of airbags, tires, floor coverings, seat upholstery, headliners, and door/side panel covering have a major share in the global technical textile (Elmogahzy YE, 2020; Kovalova N, 2019). A car seat is made of three parts: a metal armature, foam placed in a matrix (cushion), and a fabric covering the other two parts. The seat fabric in each car is approximately 3 - 5 kg (Fung et al., 2000). Automotive upholstery fabrics are typically composed of three layers: an upper surface fabric, lamination foam, and a backing fabric (Başyiğit ZÖ, 2019). The upper layer, known as the face fabric, includes various fabric constructions such as jacquard or dobby woven fabric, woven velvets, warp-knitted fabrics, raschel double-needle bar knits, and circular knits. For these face fabrics, PET-based air-texturized or friction-texturized yarns, which meet automotive industry requirements like high abrasion resistance, flame retardancy, and light fastness, are commonly used. These fabrics are engineered to offer both technical and aesthetic qualities. After the production of the face fabric, it undergoes a washing process to eliminate impurities and enhance the fabric's texture. Subsequently, the fabric is processed through a stenter machine for drying and dimensional stabilization, forming part of the finishing process. If necessary, chemical finishing is applied to meet OEM-specific standards. In the intermediate layer, polyurethane (PU) or polyester-based foam is positioned between the face fabric and the backing fabric. This foam layer provides comfort through its resilience and prevents wrinkling of the upper fabric (Kovačević S. et al., 2017). Effects of layer thickness and thermal bonding on car seat cover development. The backing fabric is typically made from PET or PA yarns, using either warp or circular knitting techniques. Its main function is to reduce friction during the seat cover's assembly by minimizing the foam-on-foam interaction between the seat and the seat cover. Various lamination methods can be employed to bond the layers, with flame lamination being the most common. In this process, heat is applied to both sides of the foam, melting the surfaces to facilitate adhesion. The face fabric and backing fabric are then pressed against the foam, forming a strong bond. This results in a three-layer composite structure that is ready for the cutting and sewing processes. Once these steps are completed, the fabric is prepared for trimming within the vehicle's interior (Smith J. et al., 2020).

Global fiber production, which was 116 million tons in 2022, reached a record level of 124 million tons in 2023. Synthetic fibers, the leader of the fiber market since the mid-1990s, account for approximately 67% of global fiber production, with a production volume of 84 million tons in 2023. Polyester is the most used and produced fiber type worldwide. Polyester fiber was produced in approximately 71 million tons and had a market share of 57% of global fiber production in 2023. Factors such as reliance on virgin fossil-based synthetic materials of the textile industry, and the difficulties in textile-to-textile recycling threaten to undermine its climate goals (Maia Research, 2024; Materials Market Report, 2024). Textile products should be sustainable, recyclable, durable, made largely from recycled fibers, free from hazardous substances, and have an eco-friendly process by 2030 according to the European Green Deal. Due to innovative fibre-to-fibre recycling, textile products at the end of their life cycle should be collected to reduce incineration and landfilling (European Union Strategy for Sustainable and Circular Textiles, 2024). The European Union (EU) aims to be an economy with net zero greenhouse gas emissions in every field by 2050 within the scope of the European Green Deal. The most well-known companies in the automotive and textile sectors have started to study replacing the materials used in vehicles with sustainable and environmentally friendly materials.

In this study, a comparable seat fabric was produced using PET yarn with added biodegradability feature for the aesthetic layer, bio-based PU foam for the lamination layer, and recycled PET yarn for the lining layer under the same conditions, structures which is already in serial production. According to international standards, mechanical tests have been performed to compare the properties of elongation at break, tenacity, and shrinkage behaviors of biodegradable and fossil-based PET yarns. The mechanical properties of produced fabrics such as abrasion, snagging, elongation, tear strength and flammability were investigated regarding to Stellantis norms. As a result of this study, It was observed that sustainable and renewable yarn and seat fabric have sufficient mechanical performance for use in the automotive sector instead of fossil-based yarn and fabric.

## MATERIALAND METHOD

### Material

The semi-dull recycled (RCY) PET chips were supplied by Indorama Company to produce partially oriented yarns (POY) in Barmag brand melt spinning machine. During the extrusion process, biodegradable additives and black colored masterbatches were added to RCY PET chips at constant dosages. Biodegradable black RCY PET POYs produced with round cross-section spinnerets had a linear density of 300 denier and 96 filaments. In the next step, the false twist texturing (FTT) process was applied to the semi-dull biodegradable recycled black PET POYs to produce 300 denier 96-filament drawn textured yarns (DTY) intermingled (IMG).

In this study, environmentally friendly and standard automotive composite fabric structures were developed. To produce the environmentally friendly automotive seat cover structure, recycled, biodegradable PES-based 300 denier, 96-filament IMG yarn was used for producing the woven face fabric. 35 density bio-PU-based foam, supplied by Recticel, was used as the lamination material. The scrim material used was a recycled PET-based, circular knitted structure. The face fabric, lamination foam, and scrim layer were laminated together using flame lamination. For producing the standard automotive seat cover structure, virgin PET-based 300 denier, 96-filament IMG yarn was used for producing the woven face fabric. 42 density PU-based foam was used as the lamination material. The scrim material used was a virgin PET-based, circular knitted structure. The face fabric, lamination foam, and scrim layer were laminated together using flame lamination. Each face fabric was subjected to 90 ºC open-width washing, 140 ºC tumble drying, and 175 ºC stentering processes under the same conditions. In the final stage of the study, the pattern-making, cutting, and sewing processes required for the production of automotive seat cover upholstery fabrics were carried out. Following these processes, the fabrics were fitted onto the seat foam to create the final product. All these processes were carried out at the Martur Company.

*Table 1. Used Materials and Production Details of the Woven Face Fabrics*

| Samples | Design Type | Yarn Type | Warp Density | Weft Density |
|---|---|---|---|---|
| Sample1 | Weft Rips 4-2 | RCY Biodegradable PET 300den 96F IMG | 32 | 17,5 |
| Sample2 | Weft Rips 4-2 | Virgin PET 300den 96F IMG | 32 | 17,5 |

**Method**

***Yarn Analysis***

The linear density (dtex/denier), tensile properties, and hot air shrinkage of all yarns were analyzed with a precision scale (Mettler Toledo, Switzerland), statimat-ME+ tensile-testing instrument (Textechno, Germany), and texturmat-ME shrinkage tester (Textechno, Germany) according to the standards such as ISO 2060, ISO 2062 and DIN 14621, respectively.

***Fabric Analysis***

Within the scope of this study, thickness, weight, combustion speed, Taber abrasion, elongation, and tear strength tests were performed on the fabrics. The tests were performed according to the methods of OEM specifications which are given in Table 2.

*Table 2. Standards used in the study*

| Test Name | Control Method | Requirements |
|---|---|---|
| Thickness | 50455/05 | mm |
| Weight | 50440 | g/msq |
| Combustion Speed | MS.90095 - 7.G2000 | max 100 mm/min |
| Taber Abrasion, 300 cycles, 1 kg Load | ASTM 3884 | Degree 3 after 300 cycles - Yarn breakage is not permitted. |
| Taber Abrasion, 600 cycles, 1 kg Load | ASTM 3884 | Degree 3 after 600 cycles - Yarn breakage is not permitted |
| Elongation, Under 10 daN Load | 50441/01 | % |
| Tear Strength | 50442 | daN |

***Determination of Fabric Thickness and Weight***

The fabric weight of the laminated fabrics was determined according to the TS EN 12127 standard. Five samples, each with an area of 100 cm², were taken from the laminated fabrics, and each fabric was weighed to calculate the average weight per square meter. The thickness (mm) was determined using a thickness gauge for textile structures. The averages of five samples were calculated for all measurements.

***Combustion Speed***
The combustion speed of the produced laminated fabrics was tested according to the FMVSS 302 standard, which utilizes a horizontal burning rate measurement method. The burning rate is measured inside a combustion chamber. The combustion chamber was used for the combustion speed test.

According to the standard, the fabric sample is cut to dimensions of 100 mm x 350 mm, and two reference lines are drawn on the sample with a distance of 254 mm between them. The fabric sample is placed on a U-shaped metal plate with its surface facing downward. The metal plate is then positioned on the holders inside the combustion chamber. The fabric sample is exposed to the flame source inside the chamber for a specified duration, behind the first reference line. If the fabric does not ignite or extinguishes before reaching the first reference line, the test result is recorded as self-extinguishing (SE). When the fabric reaches the first reference line, the timer is started. If the flame reaches the second reference line, the distance between the first and second reference points is considered. If the fabric extinguishes between the first and second reference points, the distance from the first reference point to the point where the flame extinguished is measured. According to the FIAT 9.55441 specification, the test results should be less than 100 mm/min.

***Taber Abrasion Test***
The abrasion resistance of the produced laminated fabrics was tested according to the FIAT 50455/10 standard. Taber abrasion tester was used for this test. Taber test is performed by placing a 1000-gram weight on abrasive cylindrical wheels and rotating them on the fabric surface. According to the FIAT 9.55441 specification, the Taber test is conducted with 300 cycles for automotive upholstery knitted fabrics and 600 cycles for automotive upholstery woven fabrics. There are two criteria for evaluating the test results: there should be no visible thread breaks or noticeable visual defects in the fabric structure/pattern in the areas subjected to abrasion. The outcome is assessed as either "OK" or "NOK" based on these criteria.

***Tensile Strength and Elongation Test***
The tensile strength and elongation tests of the produced laminated fabrics were carried out in accordance with the Fiat 50441/01 standard. The test samples were cut to dimensions of 200 mm ± 5 mm by 100 mm ± 1 mm, as specified in the standard. For the tensile and elongation tests, five samples were taken from each laminated fabric in both warp and weft directions. The arithmetic mean of the results from the five repeated tests conducted in each direction was calculated. The tests were performed using a Zwick brand tensile testing machine. According to the FIAT 9.55441 specification related to the standard, the elongation values should be at least 4% under a load of 10 daN. Additionally, the standard requires that the tensile strength values should be a minimum of 100 daN for woven fabrics.

***Tear Strength Test***
Tear Strength test on automotive seat fabrics was conducted in accordance with the Fiat 50442 standard. This test measures the fabric's resistance to tearing when a force is applied. Samples of the seat fabric were prepared according to the standard's specified dimensions and tested in both warp and weft directions to determine the tear resistance in each orientation. The test was carried out using a calibrated tear strength testing machine, which applies a controlled force to the fabric until it tears. The tear strength value is recorded in daN, representing the force required to propagate a tear in the fabric. According to the requirements of the Fiat 50442 standard, automotive seat fabrics must meet specific tear strength thresholds to ensure durability and resistance to mechanical damage during use.

## RESULTS AND DISCUSSION

### *Yarn Analysis*

The linear density, tensile test and hot air shrinkage test results of the yarns were given in Table 3. The yarns have similar mechanical properties to conventional PET yarns and to produce any woven fabric.

*Table 3. The results of the tensile and hot air shrinkage test of the all yarns*

| Yarns | Denier (g/9000m) | Tenacity (cN/dtex) | Elongation at break (%) | Shrinkage (%) |
|---|---|---|---|---|
| RCY Biodegredable PET 300den 96F POY | 500 | 2,2 | 137,4 | 58,8 |
| RCY Biodegredable PET 300den 96F DTY IMG | 300 | 3,0 | 20,0 | 6,2 |

### *Fabric Analysis*

Sample 2 exhibited a higher average thickness (2,61 mm) compared to Sample 1 (2,12 mm). The difference in thickness can be attributed to the materials used in each sample. Specifically, Sample 2 contains standard PET backing and virgin PET yarn, which likely contributed to its increased thickness. Regarding the average weight, Sample 2 also had a slightly higher total weight (371 g/m²) compared to Sample 1 (364 g/m²). This weight difference can be mainly attributed to the higher fabric content in Sample 2, which was 260 g/m², whereas Sample 1's fabric content was 230 g/m² (Table 4).

Both Sample 1 and Sample 2 demonstrated similar flammability behavior, as they were self-extinguishing in both longitudinal (L) and transverse (T) directions. This self-extinguishing property is a critical feature in applications where flame retardancy is necessary, indicating that both material constructions are suitable for use in environments where fire safety is a concern (Table 5). According to the Taber abrasion tests, both samples showed similar performance, maintaining a Gray Scale rating of 3 after 300 and 600 cycles. This suggests that the durability of the surface in terms of abrasion resistance is comparable for both samples, regardless of the materials used.

In terms of elongation, Sample 2 demonstrated superior performance, with longitudinal and transverse elongation values of 10,30% and 10,60%, respectively. In contrast, Sample 1 exhibited lower elongation values, with 6,40% in the longitudinal direction and 5,70% in the transverse direction (Table 6). The higher elongation in Sample 2 may be due to the properties of the virgin PET yarn and standard PET backing, which can provide better flexibility and stretch.

Regarding tear strength, Sample 1 showed slightly higher longitudinal tear strength (25,3 daN) compared to Sample 2 (23,2 daN). However, Sample 2 outperformed Sample 1 in transverse tear strength, with values of 15 daN compared to 16,8 daN for Sample 1. This indicates that Sample 1's construction, involving bio-PU foam and RCY PET scrim, provides a balance between tear strength and elongation.

*Table 4. Thickness and Weight Results of Produced Samples*

| Samples | Average Thickness (mm) | Average Weight (g/msq) |
|---|---|---|
| **Sample1** | 2,12 | Total:364 = Fabric:230 - Foam:73 - Scrim:61 |
| **Sample2** | 2,61 | Total:371 = Fabric:260 - Foam:76 - Scrim:35 |

*Table 5. Flammability Test Results of Produced Samples*

| Samples | Flammability |
|---|---|
| **Sample1** | L:Self Extinguish - T:Self Extinguish |
| **Sample2** | L:Self Extinguish - T:Self Extinguish |

*Table 6. Taber Abrasion, Elongation and Tear Strength Test Results of Produced Samples*

| Samples | Taber Abrasion 300 Cycles (Gray Scale) | Taber Abrasion 600 Cycles (Gray Scale) | Elongation Under 10 daN Load (%) | Tear Strength (daN) |
|---|---|---|---|---|
| **Sample1** | 3 | 3 | L: 6,40 - T: 5,70 | L: 25,3 - T: 16,8 |
| **Sample2** | 3 | 3 | L: 10,30 - T:10,60 | L: 23,2 - T: 15,0 |

The overall comparison suggests that the use of bio-PU foam and recycled materials in Sample 1 results in a fabric with slightly lower thickness, elongation, and tear strength properties compared to the virgin materials in Sample 2. However, the eco-friendly composition of Sample 1 may be considered advantageous for sustainable applications, where material recyclability and biodegradability are priorities. Despite these differences, both samples demonstrated excellent flame-retardant properties and comparable abrasion resistance, making them suitable for similar applications where durability and safety are essential. The choice between the two may ultimately depend on the specific application requirements, balancing sustainability with mechanical performance.

## CONCLUSION

The primary aim of this study was to produce a more sustainable, biodegradable and environmentally friendly automotive seat upholstery had suitable mechanical and flammability properties according to the automotive standards.

The yarns produced from adding biodegradable additive and black color masterbatch inside of the RCY PET polymer melt had sufficient mechanical performance like conventional and fossil-based PET yarns to produce automotive seat fabric. Automotive seat fabric performance was determined by analyzing the tear strength, tensile strength, elongation, abrasion, burning, thickness and weight of the produced fabrics. Sample 1, a sustainable and environmentally friendly fabric, and Sample 2, a conventional and reference fabric had similar thickness and weight value. Sample 1 and Sample 2 showed similar flammability performance and were self-extinguishing in both L and T directions. It has been observed that both material structures are available for use in environments where fire safety is important. Both samples had almost the same abrasion performance according to the Taber abrasion tests and were evaluated a Gray Scale rating of 3 after 300 and 600 cycles. Additionally, Sample 2 had higher elongation (at break) value than sample 1 in terms of elongation performance. Although Sample 1 demonstrated slightly higher longitudinal tear strength compared to Sample 2 regarding tear strength test results, Sample 1 underperformed Sample 2 in transverse tear performance.

In the general evaluation; although the thickness, elongation and tear strength of Sample 1 are slightly lower than Sample 2, the environmentally friendly structure of Sample 1 can provide advantages for sustainable applications. Furthermore, both samples showed superior flame-retardant performance and comparable abrasion resistance, making them available for similar applications. In conclusion, it is thought that the environmentally friendly and sustainable automotive seat fabrics produced within the scope of this project have the potential to meet automotive standards and be a green alternative.

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# AUTOMATED CUTTING OF NARROW LACE BY LASER

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**ABSTRACT**

Narrow lace is usually elastic and have complicated pattern that have to be matched perfectly and placed symmetrically on ready goods. Lingerie industry is using automated lace cutting machines to cut lace by laser beam. Lace laser cutting machines are equipped with one or two laser cutting tools. They use visual software and camera to automate graphic inspection and positioning of the lace during the cutting process. Usually the processed lace is fed on conveyor type work surface made from a stainless steel web. A special vacuum system and exhaust fans drawn away downwards the smoke particles and soiling generated in the cutting process. Automated lace cutting significantly increases work efficiency and productivity and can ensure very high cutting and pattern matching quality.

**Key words:** narrow lace, laser cutting, visual software, conveyor work surface, fume extraction

## INTRODUCTION

Narrow lace is typically used by lingerie manufacturers. On the bases of its structural qualities and design conditionally it can be divided in two groups: lace up to 10 cm wide and lace 10 – 35 (40) cm wide (see Fig.1). Both types of the lace have visually expressive woven, knitted or embroidered border patterns that are placed in all area or only along one edge of the lace [1,2].

a b

*Figure 1: Different width narrow lace: lace up to 10cm wide (a) and lace 10-40cm wide (b)*

Lace cutting is a difficult and demanding task due to its specific qualities: lace is usually elastic and have complicated pattern that have to be matched perfectly and placed symmetrically on ready goods (see Fig.2). Manual cutting of narrow lace is time and work consuming process - markers are made manually and directly onto the fabric from a half or full set of pattern pieces and cutting is performed by band knife cutting machines [2].

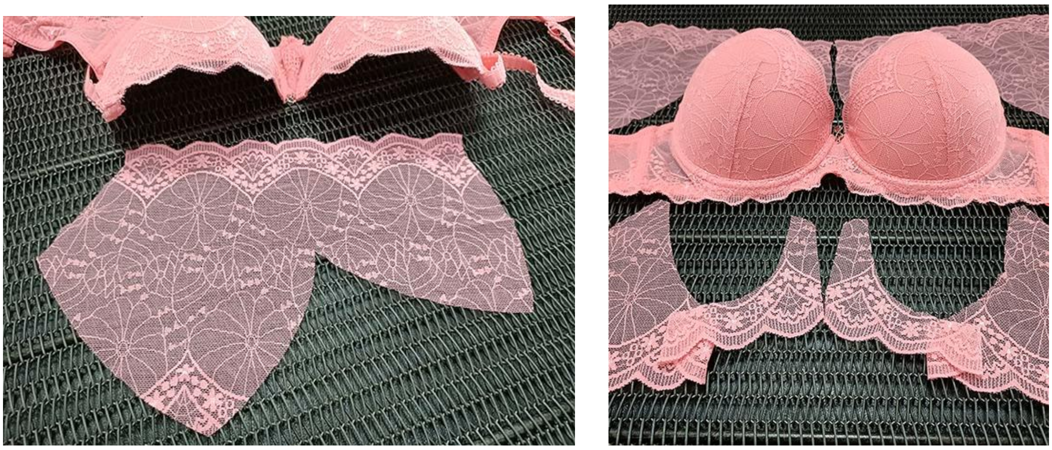


*Figure 2: Bra components cut from lace*

To improve work efficiency and cut component quality, special automated lace cutting machines are developed and used by lingerie industry. The most part of them perform narrow lace cutting process by laser beam [1,3,4,5,6].

**LACE LASER CUTTING MACHINERY**

Lace laser cutting machinery available in the market differ in: vision software versions used, the size of machine work area (400 x 800mm, 400 x 1200mm, 600x1200mm, 900x1500mm, 1000x1200mm, 1200x1500mm), numbers of laser heads fixed on the machine (one or two), laser power (100W, 130W, 150W, 180W, 300W), kind of working surface and feeding system (see 2.1.).

Lace laser cutting machinery is developed by companies: Alpha Systems (Canada), MinoWork (China), Gboslaser (China), Yueming (China), Eastern Laser (China), Hunst (China).

The main parts of lace laser cutting machines are: laser cutting tool and its motion system, vision software and vision camera, work surface and lace feeding system, and smoke and dust exhausting system [3,4,5,7].

**Laser cutting tool and its motion system**

Classical lace laser cutting machines are equipped with one cutting tool (lace cutting machines by companies: *Gbos laser*, *Kasu laser*, *Yueming*, *Eastern Laser*, *Hunst*). Some manufacturers incorporate in their machines also a second cutting tool to increase productivity, achieving high cutting speed (up to 300mm/s) and accuracy of 0,2mm for both laser heads (lace cutting machines by companies: *Kasu laser*, *Yueming*). If the machine uses two cutting heads it can perform synchronous or asynchronous movements using different control models.

Using a machine with two synchronous movement cutting tools, two laser heads are mounted on the same gantry. The dual-beam synchronous motion system, combined with the independently developed motion control software and the servo motor system, supports the cutting of two symmetrical graphics. Such laser heads cannot cut different patterns at the same time. However, they increase work process productivity double, but ensure little flexibility.

A laser cutter can be also equipped with two cutting heads that are fixed on two independent guide rails (see Fig. 3) (lace cutting machines by *Gbos laser*) . Such machine can ensure asynchronous movement of its cutting tools. The machine can cut two different shapes of lace patterns at the same time and with it increase work efficiency and productivity up to 30-50%. The cutter with two independent cutting tools can ensure several additional advantages: diversified production process; reduced production costs; more flexible production planning; increased equipment utilization; achieve multi-angle cutting of materials.

*Figure 3: Two cutting heads fixed on a laser cutter*

**Vision software and vision camera**

Narrow lace laser cutting machines are used together with an visual software and camera to automate the graphic inspection and perfect positioning of the lace during the cutting process. The high-resolution camera is fixed directly next to the cutting head. It can detect high-contrast contours cutting lace or fiducial marks on printed, embroidered, or woven patterns (cutting stickers, embroidery patches, labels, and twill numbers [8], (see Fig.4).


*Figure 4: Fiducial marks to cut a pattern*

During the cutting process the camera takes photos of the lace placed on the work surface. The vision software analyzes the photos, creates cutting file and generates the precise cutting path for the laser tool.

The visual software also can compensate pattern distortions in the lace (see Fig.5). It makes necessary corrections in actual pattern pieces thus ensuring high accuracy and cutting quality also processing lace what is imperfectly placed on the work surface or lightly distorted.

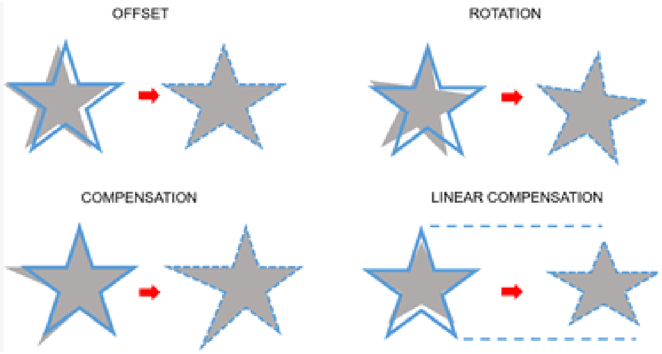



*Figure 5: Compensation of pattern distortions*

**Work surface and lace feeding system**

The work surface is made from stainless steel web (see fig. 6). It gives optimal support to thin and flexible materials like textiles. Web kind of work surface also ensures necessary work conditions for vacuum suction system and lower extraction system that are used to take away laser cutting by-products - dust and smoke (see 2.4.), [3,4,7].

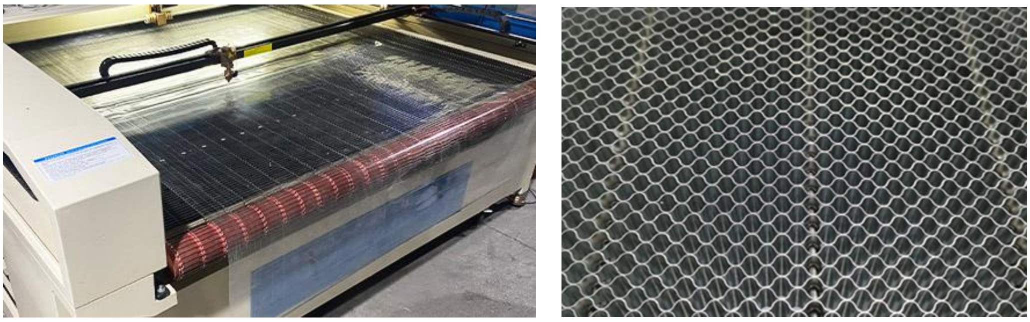
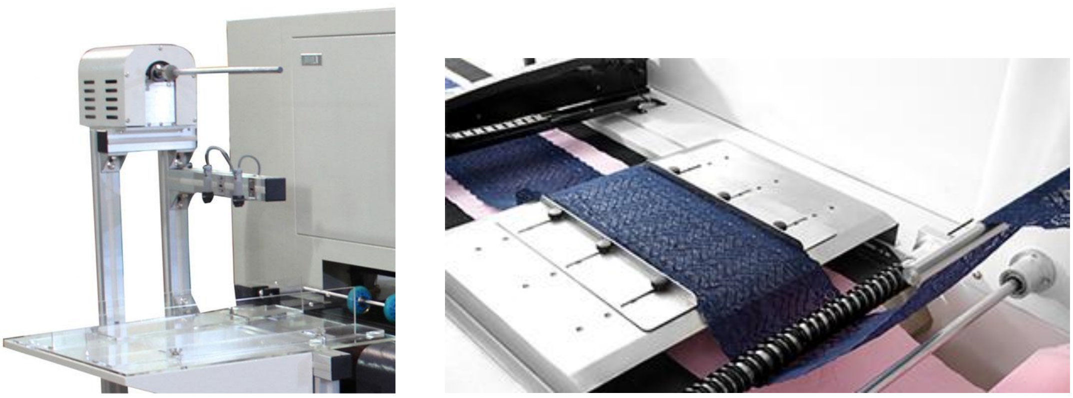


*Figure 6: Web kind work surface*

The processed lace can be fed on a fixed or a conveyor type work surface. The conveyor type work surface runs synchronously with lace feeding system of the machine and with it ensures continues work process and precise transportation of the lace without its stretching or other kind of distortions (see Fig.7). Most often a material feeder feeds the lace from a roll. There are also machines available that can process lace in a bale/flat form.



a b

*Figure 7: Lace feeding system of a laser cutting machine ETS-4012LF by Hunst (a) and MS series lace laser cutter by Gbos laser (b)*

After work process is finished in a whole laser cutting zone, the feeding system automatically unwinds the lace roll and sends the next portion to the work surface to continuous the cutting. By help of optical sensors automatic edge control is performed to ensure perfect material positioning during its feeding. Cut components are transported to pick up zone of the machine, where an operator collects them.
Some lace cutting machines use two fixed work surfaces that can be slid in and out of the work area of a laser head (see Fig.8). This kind of machines can ensure more precise positioning of the lace on a work surface and with it higher pattern matching quality.

*Figure 8: Laser Cutting Machine with a double capacity sliding working surface by company Gbos Laser*

**Fume extraction systems**

The laser cutting process produces unwanted by-products - a variety of dust, smoke, and aerosols which are generated melting and evaporating cut material. They can negatively impact cut component quality and contaminate machinery. By-products also can cause an environmental concern and pose a threat to the health of workers [9]. Lace laser cutting machines are equipped with special vacuum systems and exhaust fans to drawn away downwards the smoke particles and soiling. The fume extraction also prevent or minimize underside marks caused by cutting structure of the table.
Some lace laser cutters have fully closed contour design with doors on all four sides of the machine (see Fig.9). They can ensure better dust extraction and improved recognition effect of a vision camera.

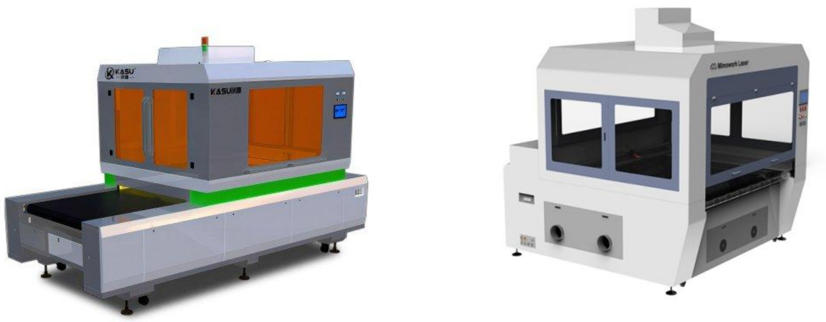


*Figure 9: Fully closed contour design of lace laser cutter by Kasu Laser (a) and Mimowork (b)*

**CONCLUSIONS**

Traditional manual narrow lace cutting method is still used by lingerie industry, however it is very much time and work consuming and cannot ensure high cutting precision. To avoid these serious disadvantages, automated lace cutting machinery is developed and available in the market for underwear manufacturers. Lace cutting is performed by a non-contact laser cutting tool, feeding narrow lace directly from a roll or a bale on a conveyer work surface. Automated lace cutting significantly increases work efficiency and productivity and can ensure high cutting and pattern matching quality what is very important in lingerie manufacturing process.

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# STRATEGİES FOR WASTE REDUCTİON FOR FLAT-KNITTED GARMENT: A STUDY ON PRODUCTİON METHODS

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**ABSTRACT**

This study aimed to examine the influence of various production methods on reducing waste in V-bed flat knitting machines, with a focus on determining the most effective approach. The research analyzed four distinct production methods: two variants of part cut (PC-1 and PC-2), simple fully fashioned (SFF), and advanced fully fashioned (AFF). Men's cardigans made from pure cotton yarn were produced to evaluate the performance of each method in terms of waste reduction. The results revealed that the advanced fully fashioned (AFF) method had the lowest waste rate, at just 2.4%, outperforming the other technique methods. In comparison, part cut 1 (PC-1), part cut 2 (PC-2), and simple fully fashioned (SFF) methods resulted in waste rates of 14.9%, 13.5%, and 8.6%, respectively. The findings of this study indicate that the advanced fully fashioned (AFF) method is the most effective in minimizing production waste in V-bed flat knitting machines. By achieving a significantly lower waste rate compared to the other methods, AFF demonstrates its potential as the optimal choice for manufacturers looking to reduce material loss and improve sustainability. These results offer practical insights for the textile industry in selecting the best production strategies to enhance efficiency and minimize environmental impact.

**Key words**: waste, flat knitting, production methods, part cut, fully fashion

## INTRODUCTION

Implementing sustainable clothing manufacturing practices is important as global resources become increasingly scarce and the population grows. A key focus in clothing production is optimizing manufacturing processes to reduce waste at every stage, ensuring a more efficient and eco-friendly approach to meeting future demands (Bukhonka N., et.al., 2024, Nemeša I., et.al., 2023, Gojic A., et.al., 2023).

Various methods are used to optimize the manufacturing process and reduce waste. Commonly used methods to minimize waste during production include optimizing pattern layout, improving fabric consumption, and reducing overall waste (Enes E., et.al., 2019) reusing and upcycling (He C., et.al., 2024, Bukhonka N., et.al., 2024, Han SLC., et.al., 2017), developing strategy zero-waste manufacturing (McQuillan H., 2019, Carrico M., et.al., 2014, Han S., et.al., 2016) and using transformable clothing designing methods (Nemeša I., et.al., 2024). By adopting these strategies, garment manufacturers can lower their environmental footprint and cut production costs. It's essential to recognize that garment production methods vary based on the type of clothing and the specific manufacturing process. Factors such as the labor required, raw material usage, time commitment, and the potential to repurpose rejected or defective materials can differ significantly across various production techniques.

The primary knitting process largely determines the quality and performance of knitted garments. Advancements in V-bed knitting machines have revolutionized production by focusing on both product quality and the technological capabilities of the equipment (Holderied P., et.al., 2023). These machines have created various fabrics, making it easier to shape pre-sized components. Manufacturers working with V-bed knitting typically use various production methods - part cut or stitch-shaped, fully fashioned, and complete or integral. The method used can significantly impact the amount of waste produced, with variations of up to 50% (Brackenbury T., 1992, Spenser D.J., 2001). The implementation of each production method necessitates the use of distinct knitting and assembly processes.

Developing whole garment or knit-and-wear V-bed flat knitting machines, and seamless warp knitting machines has led to a successful knitting industry in the 21st century (Cassidy T., 2001, Čuden A.P., 2022). These advancements have resulted in the evolution of production methods for complete knitted garments, known as the complete (integral) method. This method is achieved through knitting techniques such as whole garment or knit-and-wear, which means integrating all garment parts to produce garments in a knitting machine. By providing comprehensive data and insights, designers can effectively harness the potential of complete knitting technology to create customized garments with minimal resource consumption and production time. The complete method of garment production offers several advantages, such as eliminating joints and seams in the garment parts, reducing material waste. This method produces a high-quality seamless garment just after the knitting, particularly "ready-to-wear," reducing the steps needed to create a more efficient and cost-effective knitted garment (Peterson J. et.al., 2016, Peterson J., 20008, Choi W. et.al., 2005). This method reduces assembling production time and costs, increases productivity, and produces higher quality output than traditional methods like part cut and fully fashioned. Complete garment knitting technology has great potential to reduce manufacturing time and enable a fast delivery to customers, even within hours (Peterson J. et.al., 2008). The entire garment is produced in a single knitting process, resulting in a 3D knitted garment with a round shape. There are a few drawbacks associated with the complete method of garment production. Firstly, this technique is only suitable for a limited range of garments that do not require seams (Cassidy T., 2001, Kanakaraj P. et.al., 2021).

This research aims to investigate how different methods (part cut and fully fashioned) of knitting clothes using V-bed flat knitting machines impact production waste. The study aims to analyze the differences in production stages and evaluate their effects on production waste. By evaluating each method's impact on waste reduction, productivity, and garment quality, manufacturers can optimize processes, reduce material waste, and enhance sustainability.

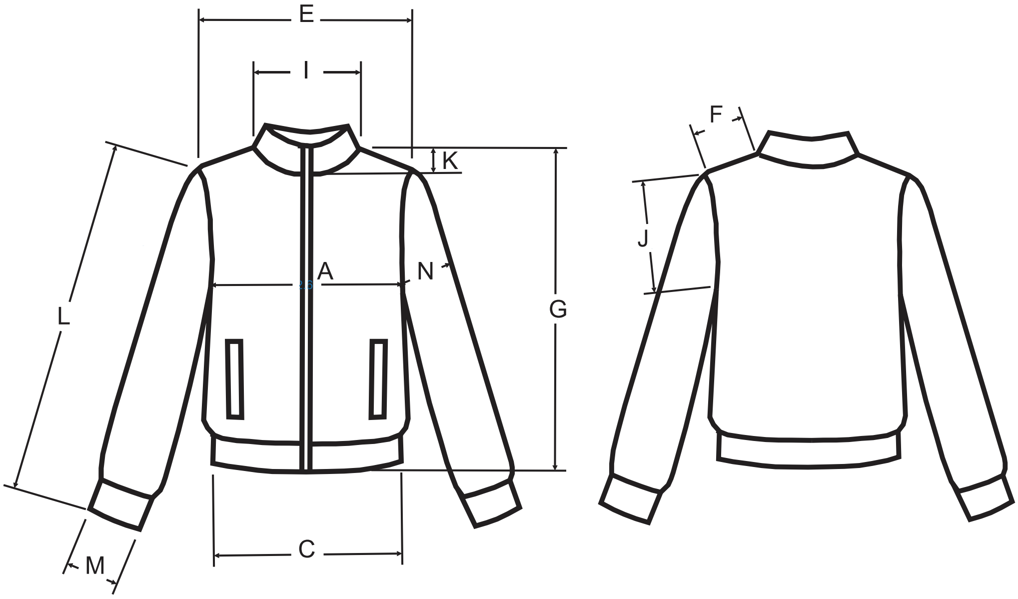
## MATERIALS AND METHODS

### *Materials*

The men's cardigan in size 42 from pure cotton yarn 50/2 Nm was chosen for this study (Figure 1). Men's cardigans were knitted on a 12-gauge CMS 340 TC-L knitting machine from Stoll, Germany. The knitted components of the cardigan (front, back, sleeves, pocket lining, front, and pocket bands) were knitted using plain stitches, while the collar, cuffs, and hem were made with 1x1 rib stitches.

*Figure 1: The men's cardigan with a zip*

The cardigan sample was manufactured accompanied by a technical sketch, presented in Figure 2. Table 1 provides a measurement chart for the cardigan to facilitate the appropriate sizing, with all measurements in centimeters. Figure 3 presents the knitted cardigan parts, and Table 3 provides their measurements.

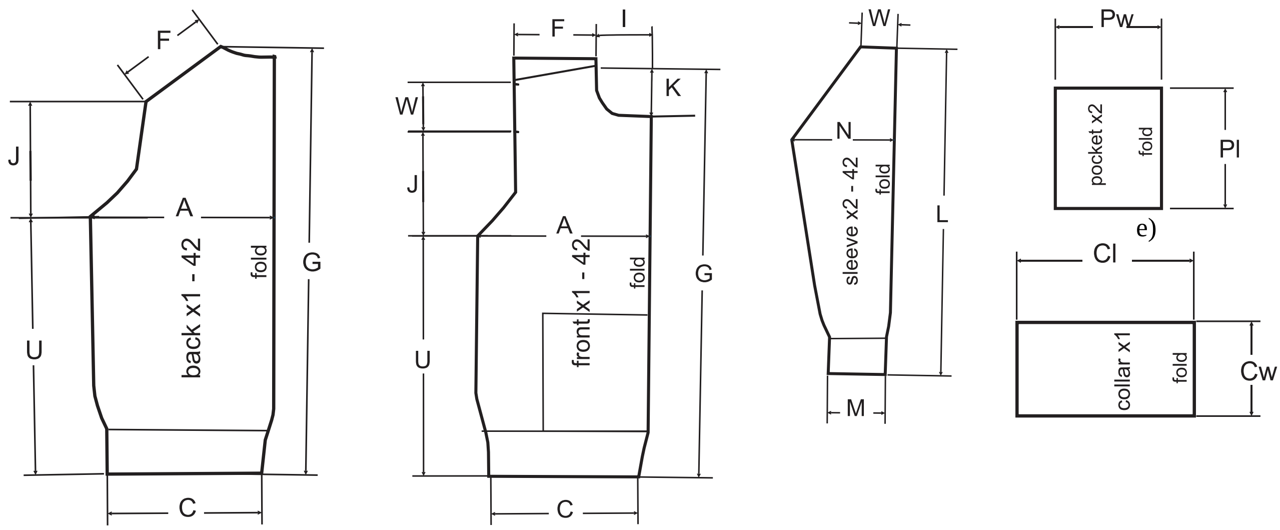



*a)* *b)*

*Figure 2: Technical sketch of the men's cardigan: a – front, b – back*

*Table 1: Men's cardigan measurement table (in cm)*

| POM | Measurement | Size range and [sample size]: 38 40 [42] 44 46 | | | | |
|---|---|---|---|---|---|---|
| | | 38 | 40 | **42** | 44 | 46 |
| **A** | Bust girth (chest width) | 56 | 58 | **60** | 63 | 67 |
| **C** | Bottom opening | 45 | 47 | **49** | 52 | 56 |
| **G** | Overall length | 67 | 69 | **71** | 73 | 75 |
| **E** | Shoulder width (seam to seam) | 45 | 46.5 | **48** | 49.5 | 51 |
| **I** | Neck width | 22 | 23 | **23** | 24 | 24 |
| **F** | Shoulder | 13.5 | 14 | **14.5** | 15 | 15.5 |
| **K** | Neck height (drop) | 8 | 8 | **8** | 8 | 8 |
| **J** | Armhole | 24 | 25 | **26** | 27 | 28 |
| **N** | Arm width | 17.5 | 18.5 | **19.5** | 20.5 | 22 |
| **M** | Sleeve opening | 9.5 | 10 | **10.5** | 11 | 11.5 |
| **L** | Sleeve length | 61 | 62 | **63** | 64 | 65 |




a) b) c) d) e)

*Figure 3: Knitted cardigan parts: a – front x1, b – back x1, c – sleeve x2, d – collar x1, e – pocket x2*

*Table 3: Measurements table for knitted cardigan parts (in cm)*

| POM | Measurement | Size range and [sample size]: 38 40 [42] 44 46 | | | | |
|---|---|---|---|---|---|---|
| | | 38 | 40 | **42** | 44 | 46 |
| | | | | **½ front part** | | |
| **A** | Bust girth (chest width) | 28.5 | 29.5 | **30.5** | 32.0 | 34.0 |
| **U** | Chest height | 39.5 | 40.5 | **41.5** | 42.5 | 43.5 |
| **C** | Bottom opening | 23.0 | 24.0 | **25.0** | 26.5 | 28.5 |
| **G** | Overall length | 68.5 | 70.5 | **72.5** | 74.5 | 76.5 |
| **K** | Neck height (drop) | 9.5 | 9.5 | **9.5** | 9.5 | 9.5 |
| **I** | Neck width | 9.5 | 10.0 | **10.0** | 10.5 | 10.5 |
| **F** | Shoulder | 13.0 | 13.5 | **14.0** | 14.5 | 15.0 |
| **J** | Armhole | 29.0 | 30.0 | **31.0** | 32.0 | 33.0 |
| | | | | **½ back part** | | |
| **A** | Bust girth (chest width) | 28.5 | 29.5 | **30.5** | 32.0 | 34.0 |
| **U** | Chest height | 39.5 | 40.5 | **41.5** | 42.5 | 43.5 |
| **C** | Bottom opening | 23.0 | 24.0 | **25.0** | 26.5 | 28.5 |
| **G** | Overall length | 66.5 | 68.5 | **70.5** | 72.5 | 74.5 |
| **W** | | 8.5 | 9.0 | **9.0** | 9.5 | 9.5 |
| **F** | Shoulder | 15.0 | 15.5 | **16.0** | 16.5 | 17.0 |
| **J** | Armhole | 17.0 | 18.0 | **19.0** | 20.0 | 21.0 |
| | | | | **Sleeve** | | |
| **N** | Arm width | 18 | 19 | **20.0** | 21.0 | 22.5 |
| **M** | Sleeve opening | 10 | 10.5 | **11.0** | 11.5 | 12.0 |
| **L** | Sleeve length | 61 | 62.0 | **63.0** | 64.0 | 65.0 |
| **W** | | 6.5 | 6.5 | **6.5** | 6.5 | 6.5 |
| | | | | **Collar** | | |
| **Cl** | Length | 45.5 | 46.0 | **46.0** | 46.0 | 46.5 |
| **Cw** | Width | 15.0 | 15.5 | **15.5** | 15.5 | 16.0 |
| | | | | **Pocket lining** | | |
| **Pl** | Length | 19.0 | 19.5 | **19.5** | 19.5 | 20.0 |
| **Pw** | Width | 35.5 | 36.0 | **36.0** | 36.0 | 36.5 |
| | | | | **Pocket band** | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **L** | Length | 5.5 | 6.0 | **6.0** | 6.0 | 6.5 |
| **W** | Width | 4.0 | 4.0 | **4.0** | 4.0 | 4.0 |
| | | | **Front band** | | | |
| **L** | Length | 73.0 | 74.0 | **75.0** | 76.0 | 77.0 |
| **W** | Width | 4.0 | 4.0 | **4.0** | 4.0 | 4.0 |

***Methods***

***Knitted parts relaxation***

The knitted pieces were washed in a fully automatic machine using the cotton cycle at 30°C. To enhance washing efficiency, 3 g/L of a wetting agent was added. The washing and drying procedures followed the ISO 6330:2021 standard.

***Determination of the production methods***

The study compares two production methods for V-bed flat knitting machines: part cut and fully fashioned. The part cut method involves knitting rectangular panels for the front, back, and sleeves, while the fully fashioned method produces stitch-shaped parts. The study explores simple fully fashioned (SFF) and advanced fully fashioned (AFF) variants, including integrated pockets. The main knitted parts for a men's cardigan, categorized by production methods, are detailed in Figure 4.

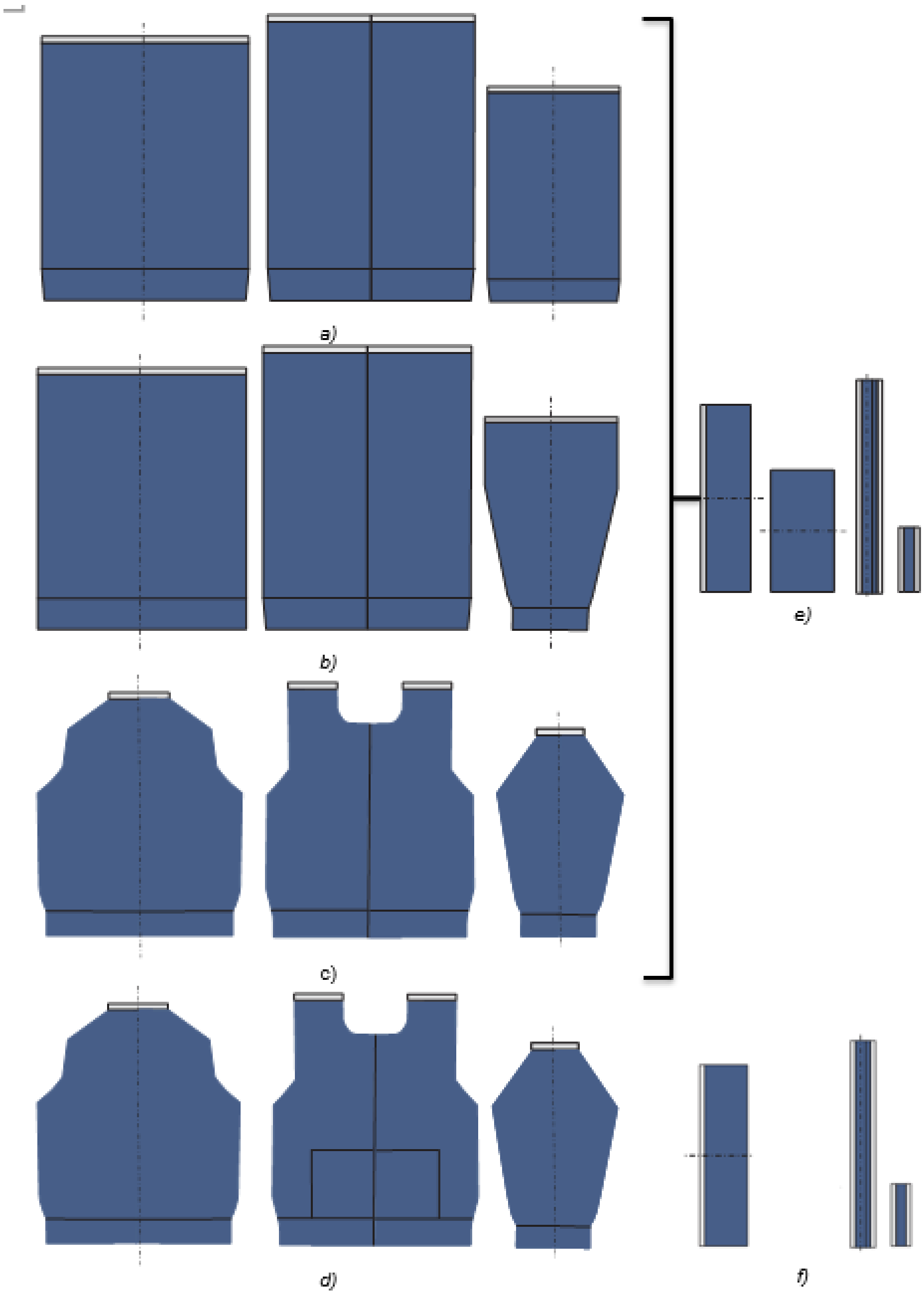



*Figure 4: The (a-d) main and (e, f) secondary knitted parts of the cardigan for different methods:*
*(a) part cut 1 (PC-1), (b) part cut 2 (PC-2), (c) fully fashioned (SFF), (d) fully fashioned (AFF)*
**main parts – back x1, front x1 and sleeve x2, **secondary parts – collar x1, lining for pocket x1, front x2 and pockets x2 bands*

*Part cut methods (PC-1 and PC-2).*

Part cut (stitched-shaped cut) is the most widely used method for producing garments on a V-bed flat-knitting machine. The process includes knitting rectangular panels (or open-width blanks) for the main parts of products, such as the front, back, and sleeves (Fig. 4, a and b), and secondary parts, such as the collars, pockets, bands, etc. (Fig. 4, e). The rectangular panels should be made according to the size of the garment, considering the lengthiest and widest measurements for each part (Brackenbury T., 1992). The distinction between the part cut 1 (PC-1) and part cut 2 (PC-2) methods lies in the shaping of the sleeves, which are knitted as a panel for PC-1 and as part shaped panel for PC-2.

*Fully fashion method (SFF).*
The fully fashioned method is a garment-making technique that involves shaping pre-sized parts of a garment using cutting-edge technology (Fig. 4, c and e). By utilizing approaches such as narrowing and widening loops in specific directions, the method produces the desired shape of the garment part that would otherwise require a cutting process. This method is a testament to the skill and precision needed in garment-making. It is a valuable technique to consider in producing high-quality garments (Brackenbury T., 1992).

*Advanced fully fashioned method (AFF).*
The advanced fully fashioned method is an innovative technique many manufacturers use now. It is based on the traditional fully fashioned method of integrating additional elements, such as pockets, into the main parts of the garment (Fig. 4, d).

## RESULTS AND DISCUSSION

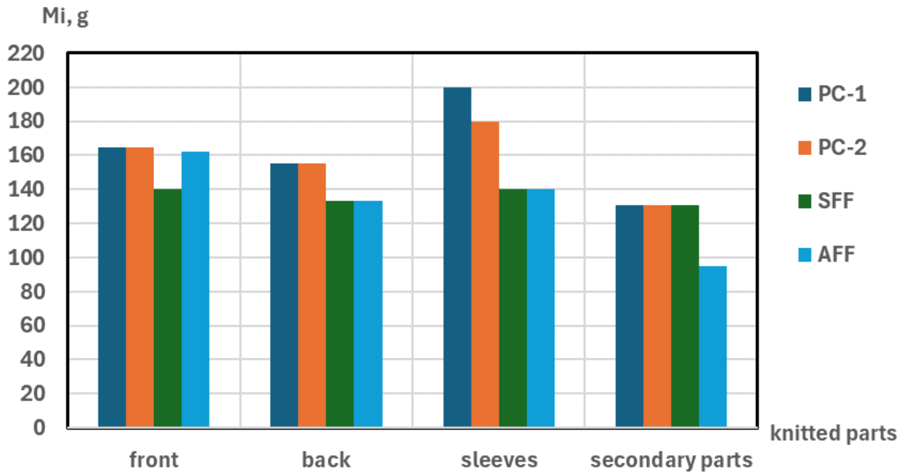
### *The waste of the knitted parts of the cardigan*
The total weight of the knitted parts $M_i$ and waste $W_i$ for four investigated production methods are presented in Figure 5.

The received results showed that the fully fashioned methods (SFF and AFF), which mean fully stitch-shaped the main knitted parts by size, showed a notable weight reduction compared to the part cut methods (PC-1 and PC-2), which means panels the main knitted parts.

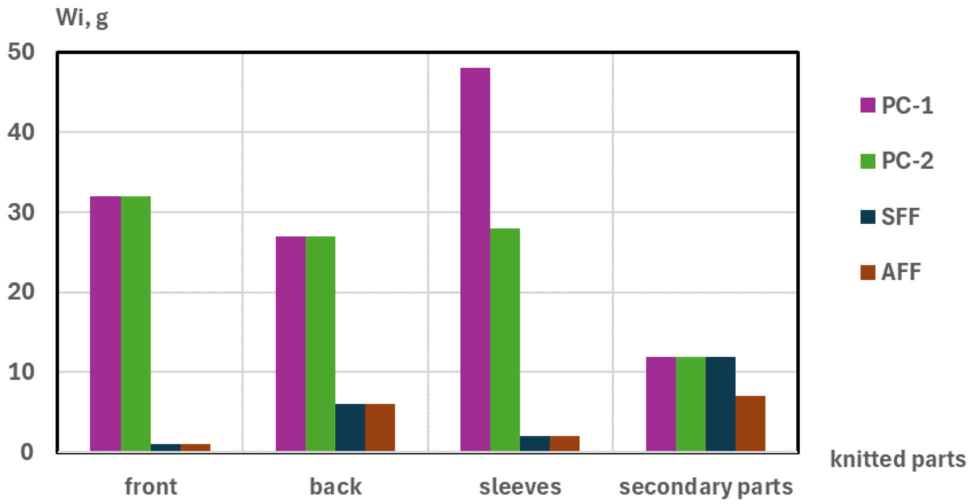
The simple fully fashioned method (SFF), in which the main knitted parts are pre-sized and shaped, offers a substantial weight reduction compared to the part cut method. Specifically, the weight of the front, back, and sleeves decreases by 10.0%, 7.7%, and 12.2%, respectively, or by 10.0% collectively from the total weight of the main parts. When using the advanced fully fashioned method, the trend for back and sleeve parts remains the same. However, the front part with integrated pockets weighs 5.3% more than the part cut method and 17.0% more than the fully fashioned method.

A comparison of the summary weight of the front part with pocket lining using part cut (PC-1) and (PC-2), as well as fully fashioned methods with the weight of the front part with integrated pockets using the advanced fully fashioned method, showed the following. The weight of the pre-sized stitched front part with pocket lining is 7.3% less than that of the panel front part with pocket lining. This difference is due to the fully fashioned method used in the pre-sized stitched front part instead of the part cut methods used in the panel front part. The weight disparity is even more significant when compared to the front part, which has integrated pockets knitted using an advanced fully fashioned method. This method results in a weight reduction of 28.8% compared to part cut methods, and 23.7% when using the fully fashioned method.

The weight of the secondary components remains constant across both part cut (PC-1 and PC-2) and simple fully fashioned (SFF) methods. The secondary parts' weight differs only in the weight of the pocket lining, which is knitted as separate panels using part cut (PC-1 PC-2) and simple fully fashioned (SFF) methods.




*a)*




*b)*

*Figure 5: The weight $M_i$ (a) and waste $W_i$ (b) of the main and secondary parts*

According to the study, the highest amount of waste is produced when using part cut methods, with a rate of 14.9%, and when using part shaped sleeves, the waste rate is 13.5%. The reason behind this difference is the variation in the shape of the sleeves – panel and part shaped. However, if pre-sized shaped main knitted parts are used, which is done through the fully fashioned method, the amount of waste decreases significantly to 8.6%. The most efficient method for reducing waste is the advanced fully fashioned method, which produces a waste rate of just 2.4%.

***Production sequence of cardigan for various production methods***

The production of a garment involves a few sequential stages, each contributing to the overall manufacturing timeline. The traditional process of producing knitted garments involves several stages: knitting, relaxation (laying up), cutting, assembling, quality control, and finishing. The production sequence may include washing and pressing or ironing for knitted garments made from natural yarns. Figure 6 presents the production sequence of men's cardigans for part cut, fully fashioned, and advanced fully fashioned methods.

It is clear that the knitting is the most important stage. However, a post-knitting phase is important for both production sustainability and clothes quality. It starts with preparing each knitted part for assembly and controlling compliance with specific requirements. The assembly stage requires carefully integrating all components into the final product, accompanied by thorough quality control to detect and rectify any imperfections. The success of each stage is critical to achieving the desired quality of the final product. Therefore, each stage must be carried out with the utmost care and attention to detail to ensure the highest quality standards. The comprehensive breakdown of manufacturing stages clarifies the distinct stages for each method that can be used for informed decision-making. The data highlights that the most significant variations in the production are observed at the knitting stage and the subsequent cutting and assembling stages. To drive in the competitive market, manufacturers must implement effective strategies to boost productivity while reducing costs and waste. By adopting innovative techniques and optimizing the process, manufacturers can find the right balance between cost savings on raw materials, production expenses, and sustainable development.

| No | PC-1 & PC-2 | SFF | AFF |
|---|---|---|---|
| 1 | Knitting blanks | Knitting garment parts | Knitting garment parts with details |
| 2 | Washing | Washing | Washing |
| 3 | Pressing or ironing | Pressing or ironing | Pressing or ironing |
| 4 | Laying up (spreading) blanks | Laying up some garment portions | - |
| 5 | Part cutting | Min part cutting | - |
| 6 | Assembly or sewing | Assembly or sewing | Assembly or sewing |
| 7 | Examine and mend | Examine and mend | Examine and mend |
| 8 | Finish press | Finish press | Finish press |

*Figure 6: Production sequence of cardigan for different production methods*

As we can see from Figure 6, the most significant differences are in the cutting stage. The part cut method requires cutting the knitted panels. In contrast, the fully fashioned method (SFF) reduces cutting the simply stitch-shaped knitted parts. Furthermore, the advanced fully fashioned method minimizes cutting. The disparity between simple fully fashioned (SFF) and advanced fully fashioned (AFF) methods lies in cutting the pocket lining which is no need for the second one.

## CONCLUSION

This study offers valuable insights into the impact of different production methods, such as part cut (PC-1 and PC-2), simple fully fashioned (SFF), and advanced fully fashioned (AFF) methods, on minimizing production waste using V-bed flat knitting technology. The advanced fully fashioned method (AFF) is more complex and expensive than the simple fully fashioned method (SFF), but it can result in significant sustainability in the knitting industry. However, the advanced fully fashioned method (AFF) impacts the cardigan's overall quality and ease of assembly. The advanced fully fashioned method (AFF) can help reduce waste production significantly. The waste rate can go as low as 2.4%, much better than other methods like part cut 1 (PC-1), part cut 2 (PC-2), and simple fully fashioned (SFF) methods (14.9%, 13.5%, and 8.6%, respectively). This highlights the importance of using efficient production techniques to minimize environmental impact and promote sustainability in garment manufacturing processes.

**Funding**

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# IMPROVING MANUFACTURING IN TEXTILE INDUSTRIES WITH INNOVATIVE COLLABORATION TOOLS

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**ABSTRACT**

This paper explores the transformative impact of integrating advanced technologies and innovative collaboration tools in textile manufacturing. The focus is on how the adoption of the Internet of Things (IoT), artificial intelligence (AI), and automation can revolutionize production processes, enhance efficiency, and improve product quality. IoT enables real-time monitoring and predictive maintenance, which helps in reducing downtime and optimizing machine performance. AI-driven quality control systems streamline operations by detecting defects early in the production process, while optimized production schedules ensure timely delivery and cost efficiency. Automation plays a crucial role in increasing productivity and precision, minimizing human errors, and enhancing the overall output quality. The study also emphasizes the importance of collaboration tools such as cloud-based project management platforms, digital twins, and virtual prototyping in facilitating seamless communication and accelerating product development. These tools enable cross-functional teams, including designers, engineers, and production managers, to work collaboratively, thereby reducing time-to-market for new products and supporting innovation. Despite the potential benefits, challenges such as resistance to change, system integration issues, and data security concerns are identified. The paper suggests that comprehensive training programs, scalable technologies, and robust cybersecurity measures are essential strategies to overcome these barriers. Furthermore, promoting lean manufacturing, sustainable practices, and enhanced supply chain transparency can significantly improve the textile industry's competitiveness and sustainability in the global market.

**Key words:** manufacturing, textile industry, collaboration tools, innovation.

## INTRODUCTION

The textile industry is experiencing significant changes due to digital transformation, which integrates advanced technologies into manufacturing processes. Digital tools and technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics, are playing crucial roles in modernizing textile manufacturing. These innovations are enabling companies to optimize their operations, improve efficiency, and enhance product quality. The adoption of Industry 4.0 principles is central to this transformation, allowing for smarter, more connected factories that can respond swiftly to market demands and production challenges (Dal Forno et al., 2023). Innovative collaboration tools are integral to this digital transformation, providing platforms for seamless communication and project management. These tools facilitate better coordination among various stakeholders, including designers, engineers, and production managers, by enabling real-time information sharing and collaborative decision-making (Ko et al., 2022). The impact of these collaborative efforts on product development within the textile industry is profound. Enhanced communication and collaboration lead to more innovative and high-quality textile products. Cross-functional teams, leveraging interdisciplinary approaches, can rapidly prototype and iterate on designs, ensuring that new products meet both aesthetic and functional requirements. Real-time collaboration tools enable continuous feedback loops, allowing for swift adjustments and improvements during the development process. As a result, companies can bring more innovative and competitive products to the market, meeting the evolving needs of consumers (Akhtar et al., 2022; Sikka et al., 2024).

Current literature on digital transformation in the textile industry focuses primarily on the technical aspects of implementing advanced technologies but often overlooks the role of innovative collaboration tools in enhancing production efficiency and product development. This paper aims to fill this gap by providing a comprehensive framework that integrates both technological advancements and collaborative tools to optimize textile manufacturing processes.

## DIGITAL TRANSFORMATION AND COLLABORATION TOOLS

The textile manufacturing industry is experiencing a profound digital transformation, integrating a wide array of advanced technologies aimed at modernizing and optimizing every aspect of the production process. This transformation is multifaceted, encompassing the incorporation of the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and automation into various stages of textile manufacturing. IoT devices are increasingly prevalent, offering real-time monitoring and control of machinery (Nouinou et al., 2023). AI and machine learning algorithms are revolutionizing the way data is analyzed in the textile industry. These technologies can process vast amounts of data, identifying patterns and predicting outcomes that would be impossible for humans to discern. In textile manufacturing, AI can optimize production schedules, enhance quality control by identifying defects at early stages, and even suggest improvements in design and materials. This results in more reliable production processes, higher quality products, and cost savings for manufacturers (Sikka et al., 2024). Big data analytics plays a crucial role in digital transformation by allowing manufacturers to extract valuable insights from the massive amounts of data generated during production. This data can include everything from machine performance metrics to supply chain logistics and customer feedback. By analyzing this data, manufacturers can identify trends, predict demand, optimize inventory levels, and make more informed decisions. For example, predictive analytics can help manufacturers forecast which products will be in high demand and adjust production accordingly, reducing waste and ensuring that resources are used efficiently (Silva et al., 2020). Automation is another key component of digital transformation in textile manufacturing. Automated systems and robotics can take over repetitive and labor-intensive tasks, freeing up human workers to focus on more complex and creative aspects of production (Alkhammash et al., 2022). Cloud-based platforms facilitate seamless communication and coordination among different teams involved in the production process. These platforms enable real-time information sharing, ensuring that all stakeholders are on the same page and can make decisions based on the most current data. This reduces the risk of miscommunication and allows for more agile and responsive manufacturing processes (Alam et al., 2023). Digital twins and virtual prototyping tools represent cutting-edge advancements in textile manufacturing. Digital twins are virtual replicas of physical assets, processes, or systems. In the textile industry, digital twins can be used to create virtual models of production lines, machinery, and even entire factories. Virtual prototyping tools enable designers and engineers to create and test digital versions of products before they are manufactured. This allows for rapid iteration and improvement of designs, reducing the time and cost associated with physical prototyping and ensuring that products are optimized for production (Alkhammash et al., 2022; (Ko et al., 2022).

These tools also facilitate better supply chain management by providing greater visibility and control over the entire production process, from raw material procurement to finished goods. For instance, real-time tracking of materials and products can help manufacturers respond more quickly to supply chain disruptions, reducing delays and ensuring that production schedules are met. Additionally, enhanced data analytics can provide insights into supplier performance, helping manufacturers make more informed decisions about their supply chain partners (Pal & Jayarathne, 2022). The ongoing evolution of digital technologies and collaboration tools promises to further transform the textile industry, opening up new possibilities for innovation and growth (Akhtar et al., 2022).

## IMPACT OF COLLABORATION AND TOOL IMPLEMENTATION

The impact of collaboration on product development in the textile industry is significant, influencing various stages of the design, production, and distribution processes. Effective collaboration supports innovation by bringing together diverse expertise from different teams, such as designers, engineers, production managers, and marketing specialists. Real-time communication and information sharing among team members ensure that everyone is aligned on goals, timelines, and expectations, which reduces the likelihood of misunderstandings and errors (Todeschini et al., 2020). Collaboration tools, such as cloud-based platforms and digital design software, play a crucial role in enhancing product development. These tools enable teams to work together seamlessly, regardless of their physical location. Virtual collaboration platforms facilitate the sharing of ideas, feedback, and revisions in real time, which accelerates the development process and ensures that products can be brought to market more rapidly. Additionally, these tools provide a central repository for all project-related documents and communications, making it easier to track progress and maintain consistency throughout the development cycle (Ko et al., 2022). Despite the clear benefits, implementing collaboration tools in the textile industry presents several challenges. One of the primary challenges is resistance to change, as employees and management may be accustomed to traditional ways of working and hesitant to adopt new technologies. This resistance can stem from a lack of familiarity with digital tools, fear of job displacement, or concerns about the reliability and security of digital platforms (Ahmad et al., 2020). Another challenge is the integration of collaboration tools with existing systems and processes. Many textile manufacturers operate with legacy systems that may not be compatible with modern digital tools. This incompatibility can lead to disruptions in workflow and data silos, where information is not easily shared between systems. To address this, companies need to invest in scalable and interoperable technologies that can seamlessly integrate with their current infrastructure (Albukhitan, 2020). Data security and privacy are also major concerns when implementing collaboration tools. The textile industry often deals with sensitive information, such as proprietary designs and customer data, which need to be protected from unauthorized access and cyber threats. Ensuring robust security measures, such as encryption, secure access controls, and regular security audits, is essential to safeguard this information. Companies must comply with relevant data protection regulations to avoid legal repercussions and maintain customer trust (Shen et al., 2021). Leadership support is also crucial, as management needs to champion the adoption of new tools and demonstrate their commitment to digital transformation (Pal & Jayarathne, 2022). Addressing these challenges requires a strategic approach that includes comprehensive training, scalable technologies, robust security measures, and strong leadership support (Albukhitan, 2020). Based on the analyzed literature, a theoretical model is developed to illustrate how the integration of advanced technologies and innovative collaboration tools can improve textile manufacturing processes. The model, presented in Figure 1, highlights the synergistic relationship between IoT, AI, automation, and collaboration tools such as digital twins and virtual prototyping.

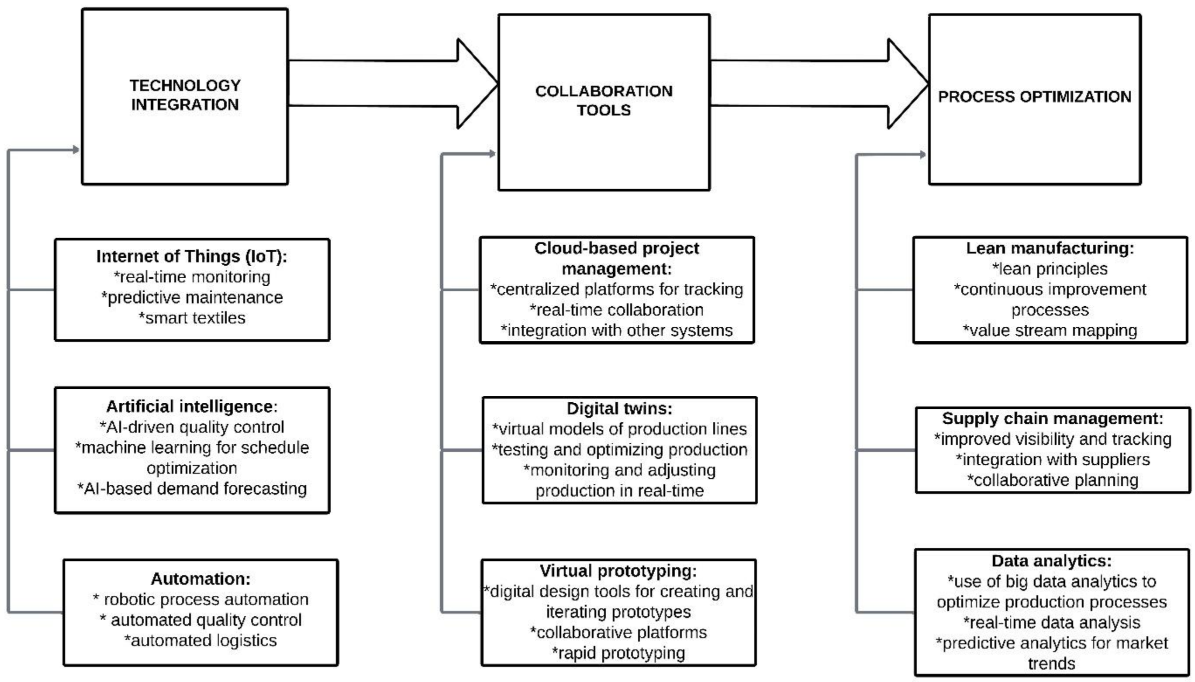


*Figure 1: Model for improving manufacturing in textile industries*

The integration of technology, particularly the Internet of Things (IoT), enhances the efficiency and reliability of textile manufacturing. IoT enables real-time monitoring of machinery and processes, allowing continuous data collection and predictive maintenance, reducing downtime and costs. Additionally, IoT-powered smart textiles offer new functionalities, adding value and differentiation in the market. Artificial intelligence (AI) is critical in improving quality control and production optimization. AI-driven systems detect defects more accurately and quickly than traditional methods, reducing waste and ensuring higher product standards. Machine learning algorithms optimize production schedules by analyzing data and predicting market demands, while AI-based demand forecasting aligns production with consumer needs. Automation plays a key role in boosting productivity, with robotic process automation (RPA) handling repetitive tasks, freeing workers for more complex roles. Automated inspection systems ensure precision in quality control, and material handling automation streamlines logistics, improving production speed. Collaboration tools, such as cloud-based platforms, improve coordination and communication, centralizing project tracking and updates in real-time. Integration with other enterprise systems enhances workflow management, reducing miscommunication and delays. Digital twins simulate production scenarios, allowing manufacturers to test changes virtually, reducing risks and downtime. Real-time monitoring with digital twins ensures efficiency in manufacturing processes. Virtual prototyping tools enable rapid iteration of product designs, speeding up time-to-market and improving quality by identifying issues early. Lean manufacturing principles, such as waste elimination and continuous improvement, are central to process optimization. Value stream mapping identifies inefficiencies for actionable improvements. Supply chain management is enhanced by better material tracking and just-in-time inventory management, reducing excess costs and improving scheduling. Collaboration with supply chain partners ensures aligned planning and forecasting, boosting overall responsiveness. Data analytics supports process optimization through insights that drive decision-making. Big data and real-time analysis optimize production, while predictive analytics helps anticipate market trends and production needs, allowing proactive adjustments.

## SUGGESTIONS AND GUIDELINES

Based on the developed theoretical model and the reviewed literature, the following guidelines and suggestions are proposed for effectively integrating advanced technologies and collaboration tools into textile manufacturing:

- Governments and enterprises should allocate funds to R&D initiatives focused on IoT, AI, and automation in textile manufacturing. This investment will drive innovation and ensure that the industry remains competitive on a global scale.
- Enterprises need to develop and offer extensive training programs to help employees adapt to new technologies and collaboration tools. This ensures a smooth transition and maximizes the potential benefits of technological advancements.
- With the increased reliance on digital tools, both governments and enterprises must prioritize robust cybersecurity protocols to protect sensitive data. Regular security audits and employee training on cybersecurity practices are essential to mitigate risks.
- Establishing standardized guidelines for the implementation of digital tools and collaboration platforms can help ensure consistency and interoperability across the industry. These standards can be developed through industry consortia or governmental bodies.
- Enterprises should invest in technologies that provide greater visibility and traceability throughout the supply chain. This can help improve inventory management, reduce delays, and respond more effectively to market demands.
- Enterprises should utilize big data analytics to gain insights into production processes, market trends, and customer preferences. These insights can inform strategic decisions and help optimize operations for better efficiency and product quality.

## CONCLUSION

The textile manufacturing industry stands at the cusp of a significant transformation driven by the integration of advanced technologies and innovative collaboration tools. This research highlights the crucial role that digital transformation plays in modernizing textile manufacturing processes, with technologies such as the Internet of Things (IoT), artificial intelligence (AI), and automation providing substantial improvements in efficiency, quality, and responsiveness.

Future research should focus on empirical studies to validate the proposed theoretical model by analyzing case studies of textile companies that have successfully integrated advanced technologies and collaboration tools. Comparative studies between different regions or textile sub-sectors could provide insights into the unique challenges and opportunities associated with these technologies. Additionally, research could explore the impact of organizational culture and leadership on the successful adoption of these tools and the role of government policies in supporting digital transformation in the textile industry.

## ACKNOWLEDGEMENT

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# OVERVIEW OF STUDIES REGARDING SUSTAINABLE MANAGEMENT IN THE TEXTILE INDUSTRY

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**ABSTRACT**

This paper explores sustainable management in the textile industry, focusing on sustainable business methods and practices. The textile sector is a major contributor to environmental degradation due to its intensive use of resources and harmful production processes. Paper highlights the need for adopting eco-friendly materials, reducing water and chemical use and transitioning to renewable energy. Circular economy approaches, such as designing durable garments and promoting textile recycling, offer pathways to reduce waste. Technological innovations, including automation and waterless dyeing, present solutions for resource efficiency but require broader adoption. The paper emphasizes the importance of collaboration between governments, enterprises, and consumers to achieve sustainable management. It concludes that while significant challenges remain, a combined focus on environmental, social, and technological strategies can help the industry move towards complete sustainability.

**Key words**: Sustainable management, Textile industry, Circular economy, Technological innovations, Social responsibility.

## INTRODUCTION

Sustainable management in the textile industry has become an increasingly notable subject of research due to the sector's significant environmental and social footprint. The textile industry is known for its intensive use of water, chemicals, and energy, along with its contribution to global pollution. As the global demand for textiles rises, the necessity for sustainable practices has intensified. Various studies have emerged to address the ways in which the industry can reduce its negative impact and transition towards more sustainable operations. These studies range from exploring the environmental and social implications of textile production to investigating innovative technologies that can contribute to more sustainable outcomes (Okafor, 2021).

A significant number of studies addresses the environmental impact of textile manufacturing and the initiatives that can mitigate this damage (Esteve-Turrillas, 2017; Sandin, 2018; Buscio, 2019). The production processes associated with textiles often involve high volumes of water, energy, and harmful chemicals, leading to water pollution and significant carbon emissions. Researchers have investigated the environmental consequences of these practices, providing data on the scale of pollution and resource depletion caused by the industry. For example, some studies highlight the issue of water contamination due to dyeing and finishing processes, which contribute to the degradation of local ecosystems and water supplies in manufacturing regions. In response to these challenges, there has been a focus on sustainability initiatives that seek to reduce this environmental damage. This includes the development of eco-friendly materials, such as organic cotton or recycled polyester, which require fewer resources to produce and are less harmful to the environment. Further, sustainable manufacturing processes, such as waterless dyeing technologies and the use of renewable energy, have been investigated for their potential to lower the ecological impact of textile production (Yacout, 2016). These studies provide a crucial foundation for understanding how the industry can shift towards greener practices while meeting consumer demand.

Another important area of study in sustainable management relates to the adoption of circular economy models within the textile industry. A circular economy focuses on minimizing waste and maximizing the reuse of materials, in contrast to the traditional linear model of production and disposal. In the context of the textile sector, this involves strategies such as designing clothes for longer use, recycling fibers, and establishing closed-loop systems where textiles are continuously repurposed. Studies have examined how circular economy principles can be applied to reduce the overall material footprint of the industry. Research often emphasizes the importance of extending product lifecycles by improving clothes durability and encouraging repair and reuse. This approach not only reduces waste but also decreases the demand for virgin materials, which further reduces environmental pressures (Jia, 2020; Chen, 2021)

Technological innovations have also emerged as a major area of study in the pursuit of sustainable production processes. New technologies have the potential to significantly reduce the environmental and social impacts of textile manufacturing (Alam, 2023). Advances in automation, for example, can optimize resource use by reducing energy consumption and waste. Artificial intelligence and data analytics are being used to predict demand more accurately, minimizing overproduction and unsold inventory, which are common sources of waste in the fashion industry. Additionally, innovations in dyeing techniques, such as the development of waterless dyeing technologies, are being researched as a way to address the significant water usage associated with traditional methods. Furthermore, the growing field of smart textiles, which includes fabrics that can respond to environmental stimuli or monitor health conditions, is opening up possibilities for new, sustainable product designs that reduce the need for frequent washing or replacement. Hovewer, while these technological innovations hold great promise, they need to be made cost-effective and scalable to have a widespread impact across the global industry (Cherenack, 2012).

Sustainable management within the textile industry encompasses a broad range of topics, from environmental initiatives and circular economy models to social responsibility and technological innovation. The complexity of the challenges faced by the industry means that no single solution is sufficient. Instead, sustainable management will require a multifaceted approach, combining new technologies, ethical practices, and collaborative efforts across all levels of production.

## METHODOLOGY

### The subject and the problem of research

This paper will consider the importance of sustainable management practices in the textile industry. Also, this paper will present the benefits of sustainable management. The paper will not be focusing on specific aspect, rather try to observe as many different studies as possible.

### Research goal

The goal of this paper is to present the role and the importance of sustainable management in the textile industry, as well as to give practical recommendations for improving textile companies operations.

### Research question

Based on analyzed theories and studies, we will try to answer the following question:
RQ1: How can sustainable practices and methods in the textile industry improve general sustainable management?

### Research method

This is a form of theoretical research in which conclusions are made by studying previous conducted researches. Research will consider different studies of other authors and analyze their results in order to make universal conclusions.

## RESULTS AND DISCUSSION

The environmental impact of textile manufacturing has been a significant area of research, given the extensive resource use and pollution associated with the industry. Textile production requires large amounts of water, energy, and chemicals, making it one of the most resource-intensive industries globally. Studies have highlighted the extent of the environmental damage caused by processes like fiber cultivation, dyeing, and finishing. Cotton, for example, is a widely used natural fiber but is highly water-intensive, often leading to wasting of water resources in regions where it is cultivated. Synthetic fibers like polyester, on the other hand, are derived from petroleum and contribute to the fossil fuel consumption and greenhouse gas emissions. These fibers also contribute to microplastic pollution, which has become a major environmental concern due to its impact on marine ecosystems. The textile industry, therefore, plays a considerable role in environmental degradation, particularly in regions where regulations are poorly enforced. Identifying and promoting sustainability initiatives aim to mitigate these environmental impacts. Alternative materials include fibers made from recycled materials, such as recycled polyester, which reduces the need for virgin petroleum and minimizes waste, as well as the use of plant-based or biodegradable fibers, which have a lower environmental footprint. These materials not only require fewer inputs during production but also degrade more easily at the end of their lifecycle, reducing the long-term impact on landfills (Kalia, 2013; Subash, 2021).

In addition to alternative materials, innovations in the production process itself have been an important point of sustainability research. Technologies that reduce water and chemical use during dyeing and finishing have shown promise in lowering the ecological footprint of textile manufacturing. Waterless dyeing technologies, for example, significantly reduce the water and chemical consumption. These technologies not only conserve water but also minimize the risk of water pollution (Islam, 2021). Renewable energy sources, such as solar or wind power, are also being explored as ways to reduce the industry's reliance on fossil fuels. Studies suggest that shifting towards renewable energy can help lower the carbon emissions of textile manufacturing, though there are challenges in implementing these solutions at a global scale, especially in regions with limited infrastructure for renewable energy (Palamutcu, 2017; Choudhury, 2017). In parallel with these environmental efforts, research on circular economy models within the textile sector has gained considerable attention as a promising approach to sustainability. The traditional linear model of production, consumption, and disposal has led to large amounts of textile waste, much of which ends up in landfills or incinerators. Circular economy models aim to close this loop by designing products and systems that keep materials in use for as long as possible. This can be achieved through a variety of strategies, including designing clothes for durability, encouraging reuse and repair, and recycling textiles into new products (Furferi, 2022). Extending the lifecycle of textiles can significantly reduce the demand for new raw materials, thereby lowering the environmental impact of the industry.

Smart textiles and fabrics are another important area of technological innovation with implications for sustainability. Smart textiles are fabrics embedded with technology that allows them to respond to environmental conditions or interact with the wearer. For instance, some smart fabrics can regulate temperature or track health metrics, which can reduce the need for frequent washing or replacements, thereby lowering the environmental impact of product care and disposal. Studies have also looked into how these fabrics can be designed with sustainability in mind, incorporating recycled or biodegradable materials that reduce waste. While smart textiles are still relatively niche, they point to a future where fashion and function intersect in ways that promote sustainability (Schneegass, 2017).

The social responsibility aspect of sustainable management in the textile industry has become increasingly important, particularly as consumers and stakeholders demand more ethical practices from companies. Historically, the textile and fashion industries have been criticized for labor rights violations, including poor working conditions, low wages, and child labor, especially in developing countries where much of the manufacturing takes place. These practices have been enabled by the global nature of the supply chain, where companies often outsource production to regions with less stringent labor regulations in an effort to reduce costs. Studies have highlighted the human cost of these practices, calling attention to the need for more ethical and socially responsible management within the industry (Đorđević, 2019). Research in this area often focuses on how companies can align their operations with sustainable development goals that emphasize decent work conditions and economic growth. Implementing socially responsible practices typically involves ensuring that workers are paid fair salaries, provided safe working environments, and granted basic labor rights. Studies explore how companies are adopting these principles by improving their transparency and traceability throughout their practices (Szewczyk, 2016; Dixit, 2019).

Significant challenge in ensuring ethical management in the textile industry is the tension between sustainability and profitability. Many studies have shown that adopting socially responsible practices can increase costs for companies, particularly in a competitive market driven by the demand for cheap, fast fashion. This tension creates a challenge for companies that want to be more ethical but feel constrained by the need to maintain profitability. However, researchers have also highlighted the growing business case for ethical management, as consumers, particularly in developed markets, are increasingly willing to pay a premium for sustainably and ethically produced goods. Brands that successfully integrate social responsibility into their business models often benefit from enhanced brand loyalty and a positive corporate image, which can offset some of the costs associated with implementing these practices (Lee, 2017).

## GUIDELINES AND RECOMMENDATIONS

Based on analyzed theory, the following guidelines and recommendations for improving sustainable management in the textile industry are provided:

- Governments should enforce environmental regulations on textile manufacturing – Stricter water usage and waste management regulations can motivate companies to adopt eco-friendly technologies.
- Government bodies should provide funding for research and development in sustainable textile technologies - Investments in waterless dyeing and renewable energy solutions will allow for more rapid development and deployment of sustainable practices.
- Governments should implement consumer awareness campaigns focused on sustainable fashion - Educating the public about the environmental and social impacts of their clothing choices can shift consumer behavior towards more sustainable practices.
- Enterprises should adopt circular economy models to minimize waste – Companies can design products with durability and recyclability in mind, reducing the demand for new raw materials.
- Enterprises should explore innovative uses of recycled materials and eco-friendly fabrics - By incorporating materials like recycled polyester or biodegradable fibers, companies can significantly reduce their environmental footprint.
- Enterprises should invest in technological innovations that improve efficiency and reduce resource use - Using renewable energy and water-efficient technologies in manufacturing will reduce the industry's overall environmental impact.
- Individuals should reduce textile waste by purchasing higher-quality, durable clothing - Buying fewer, longer-lasting products and repairing them when needed can help break the fast fashion cycle.

Consumers should also support brands with clear sustainability commitments to drive market demand for eco-friendly products.

- Individuals should engage in responsible disposal practices for old clothing – Donating and recycling old clothes can reduce the amount of textile waste that ends up in landfills. Supporting textile recycling programs will help drive demand for more circular systems within the industry.

## CONCLUSION

The textile industry faces several important challenges as it seeks to transition towards more sustainable management, driven by its significant environmental and social impact. This paper explored various dimensions of this transition, focusing on how the integration of circular economy models, ethical management practices, and technological innovations can contribute to global sustainability. Studies on environmental sustainability have highlighted the extensive resource use in textile manufacturing, emphasizing the urgent need for initiatives that reduce water, chemical, and energy consumption. At the same time, research into circular economy and social responsibility approaches offers promising pathways to minimize waste and establish ethical practices. Technological innovations have shown great potential in addressing both environmental and social challenges within the industry. Advanced technology can help reduce waste, optimize resource use, and provide greater transparency of business operations. However, the affordability of these solutions are still issues that need to be addressed, particularly for smaller companies and those operating in regions with limited access to such innovations. The findings suggest that while sustainable approaches offer significant potential, the textile industry must address several barriers before achieving complete sustainability. Collaboration between governments, enterprises, and consumers is crucial in driving this change. Governments must enforce regulations and provide financial support for research and development. Enterprises need to commit to long-term strategies that prioritize sustainability over short-term profit, and individuals must become more conscious of their consumption and disposal habits (RQ:1). Only through coordinated efforts across different sectors, the textile industry can move towards sustainable management that balances environmental protection, social responsibility, and economic viability.

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# ZERO-WASTE CLOTHING USING FABRIC SHIRRING TECHNIQUE

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**ABSTRACT**

Two concepts - minimal waste design (MWD) and zero waste design (ZWD) - can be used to support waste reduction idea in fashion industry. MWD concept is actual in garment industry currently. The great samples of ZWD are traditional folk costumes of different nations. Currently ZWDs are rarely seen in industrial garment collections. Fabric shirring as a simplified designing and pattern making method could be used to create industrially manufactured MWD or ZWD garments. Fabric shirring can be easy performed by specialized multi needle sewing machines. Three different shirring methods are used: elastic thread inserted in needles; elastic thread as a looper thread; elastic thread as the third thread. In garment industrial manufacturing process the fabric shirring technique can ensure several benefits: simplified pattern making process, minimized or fully eliminated pre-consumer textile waste, production of garments in reduced number of sizes, simplified manufacturing process.

**Key words:** minimal waste design, zero waste design, fabric shirring, multi needle sewing machines

## INTRODUCTION

Currently the fashion industry creates huge amounts of textile waste that negatively impacts the environment. To improve the very critical situation, society demands to use new, more ethical and sustainable practices in the apparel manufacturing process. Traditionally the responsibility for minimalizing of fabric waste is placed on a pattern maker and the material cutting processes. However, the textile waste should be eliminated much earlier - already at the designing phase of a product.

Two concepts supporting waste reduction idea are known in the fashion industry - minimal waste design (MWD) and zero waste design (ZWD). MWD is a garment development process that uses different methods to reduce material waste to minimum [1,2,3,4]. This concept is actual in the garment industry currently. Because of growing textile material prices and consumers' demand for lower priced garments, the industry uses different technologies - marker making and cut planning software, automated cutting systems - to reduce material consumption, and pre-consumer fabric waste.

ZWD refers to designing garments with no fabric waste at all (or the waste is used to create other products or is recycled) [4,5,6]. Several different techniques can be used to create design with zero material waste. Fabric draping and knitting are the most well-known methods [1]. Garment patterns can also be made like a puzzle - using whole pieces of fabric without any fabric waste [7].

## ZERO WASTE DESIGN CONCEPT

Garments created from piece of whole width fabric, so called "zero-waste garments" are not a new phenomenon. Already many centuries ago and even a thousand years ago traditional clothing of many nations was created from different length whole fabric pieces just draping them around a human body. Well-known samples are *himation*, *chiton* and *peplos* in ancient Greece and *sari* and *dhoti* in India [8,9]. The great samples of ZWD are also traditional folk costumes of different nations. The hand woven fabrics were precious resource, and any waste of them creating clothing was not tolerated. Most often, garments were shaped from rectangular material pieces draping, pleating, folding, shirring and, at the end stitching them together [8,9]. The idea of ZWD became actual again at the end of the 20th century when several designers, such us, Martin Margiela, Issey Miyake, Rei Kawakubo i Yohji Yamamoto started to use ZWD methods in their fashion collections [9]. Till know ZWDs are rarely seen in industrial garment collections. 100% use of textile material to create a garment style requires a new way of thinking and untraditional creativity from designers. However, using traditional pattern making methods possibilities to reduce fabric waste are already very much limited and technical progress cannot add new ones, too [10]. Now it has to be done with the help of designers creating advanced garment styles with minimal or no material waste at all.

**FABRIC SHIRRING TECHNIQUE**

Fabric shirring in one of the old sewing techniques widely used to create folk costumes. Shirring is a fabric decoration principle when two or more parallel seams are stitched and gathered on the material surface (see Fig.1). Traditionally fabric shirring was used on the waist, sleeves, neck line, and other places [11]. In folk garments the shirring had two important tasks - it had to decorate and shape separate their parts.

*Figure 1: Fabric shirring*

The shirred fabric part gets specific 3D surface decoration. The obtained effects depend on fabric properties, shirring level (how much the material is gathered), number of parallel seams and their mutual placement. Changing the shirring volume, makes it possible to change the shape and dimensions of garment components (see Fig.2). Shirring can be performed with ordinary sewing thread or using special elastic thread [11,12]. The shirring technique is very effective in designing clothing from light fabrics.

*Figure 2: Shirred waist and neck line of the Hungarian vintage blouse*

The shirring as a simplified designing and pattern making method could be successfully used again creating industrially manufactured MWD or ZWD garments.

**MULTI NEEDLE SEWING MACHINES FOR FABRIC SHIRRING**

In industrial manufacturing conditions shirring can be easily performed by widely available specialized multi needle sewing machines (see Fig.3) [13]. These machines are equipped with large number of needles and loopers to create an unlimited number of parallel seams of single thread chainstitches 101or double thread chainstitches 401 (see Fig.4) [14].

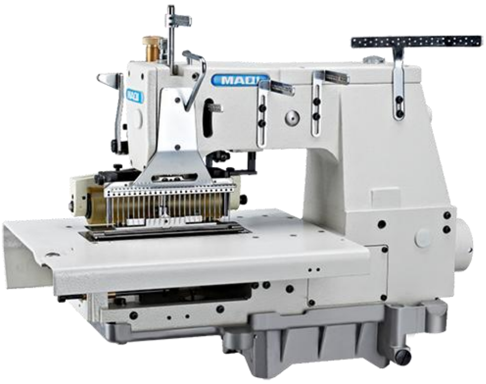


*Figure 3: Multi needle sewing machine*

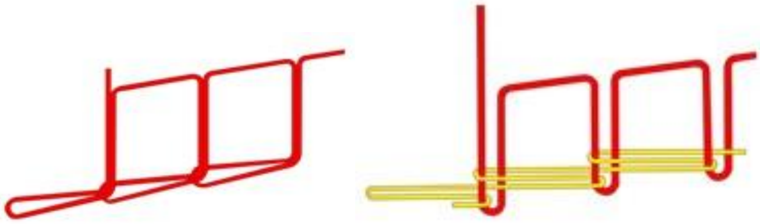



*Figure 4: Stitch type 101 (a) and stitch type 401 (b)*

The multi needle sewing machines can use different *needle gauge sets* with different total numbers of needles (see Fig. 5). Changing the needle gauge sets and the number of needles set in them, as well as, using appropriate attachments, the machines can also be used for other applications: elastic band attaching/ inserting, pin-tucking and smocking.

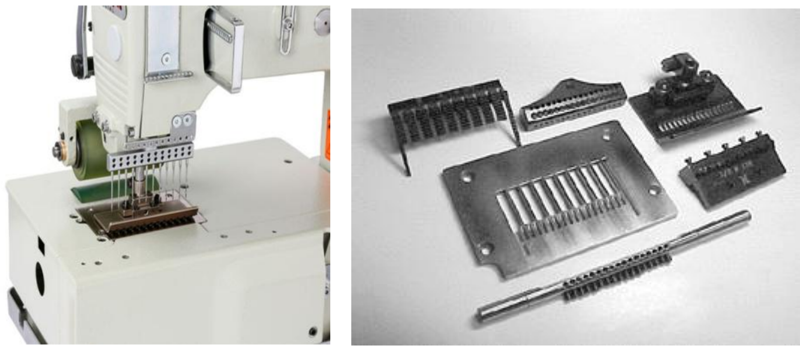


*Figure 5: Full needle gauge set*

The multi needle machines use a *bottom feed system* and *rear pullers* (see Fig. 3,5). Advanced multi needle machines (Siruba, Yamato, others) can be equipped with *pneumatic under thread trimming device*. After the threads are cut off, a machine *wiper* blows them up over the presser foot to start a new sewing cycle.

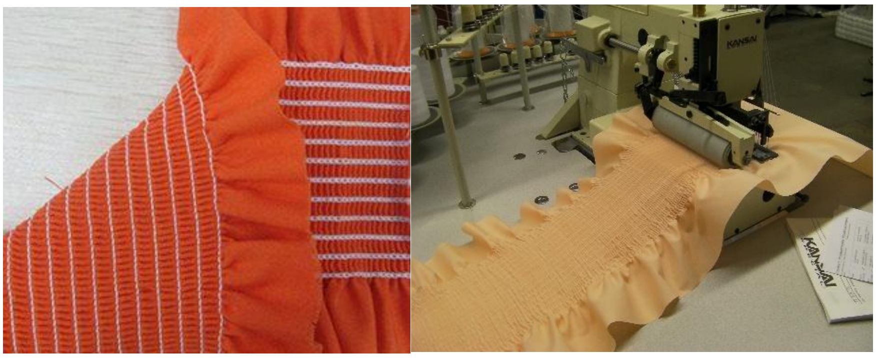
Depending on the application several other devices use to be mounted on the machines: a top or bottom metering device, elastic expander rolls, a pin-tucking device, and a smocking device. Multi needle sewing machines are manufactured by companies such as Kansai Special, Siruba, Sakura Stitch, Japsew, and others.

## FABRIC SHIRRING TECHNIQUES

The fabric shirring with the multi needle machine can be done using one elastic thread. Three different shirring methods are used: elastic thread inserted in needles; elastic thread as a looper thread, and elastic thread as the third thread [11,15].

### Shirring with an elastic needle thread

The elastic thread goes through the needles of the machine. Usually the loopers do not have any thread, and the machine creates single thread stitches 101 (see Fig.6). This kind of shirring is suitable for thin fabrics or light knitwear (see Fig. 3a). A metering device mounted above the machine is used to stretch the elastic thread evenly (see Fig. 6).



a b

*Figure 6: Shirring with single elastic thread and stitches 101 (a) a machine for shirring with a metering device on the top for elastic needle threads (b)*

### Shirring with elastic looper thread

The elastic thread is used as a looper thread while needles have standard thread creating stitch type 401. As the elastic thread is thicker than the standard thread, the loops can make stiff the shirred fabric part. This shirring method is preferable for medium light fabrics, also for parts of garments where additional stiffness is necessary (waist, cuffs).

### Shirring with the third elastic thread

Using this shirring technique every seam is created from three threads. Needles and loopers use standard thread creating stitch type 401. The elastic thread is fed through metering device fixed below the machine in front of the needles (see Fig.7). Making stitches the elastic thread is wrapped with the needle and looper threads. In the seam it stays straight, it does not make loops and it does not make the shirred fabric part stiff (Siruba, Kansai Special). This method is preferable for light fabric shirring.

*Figure 7: Shirring with the third elastic thread and a bottom metering device for elastic threads*

## BENEFITS OF FABRIC SHIRRING TECHNIQUE MANUFACTURING GARMENTS

Using elastic thread the shirred fabric part gets stretchy. It helps to get the perfect fit on a human body not cutting the fabric in pre-shaped components (see Fig.8). In the garment industrial manufacturing process the elastic fabric shirring technique can ensure several very important benefits:

- eliminated or simplified the pattern making process,
- minimized or fully eliminated pre-consumer textile waste.
- production of garments in the reduced number of sizes (clothing item can be worn by consumers of more than one size group),
- simplified manufacturing process - pattern making, cutting, sewing,
- lower price level of ready goods.

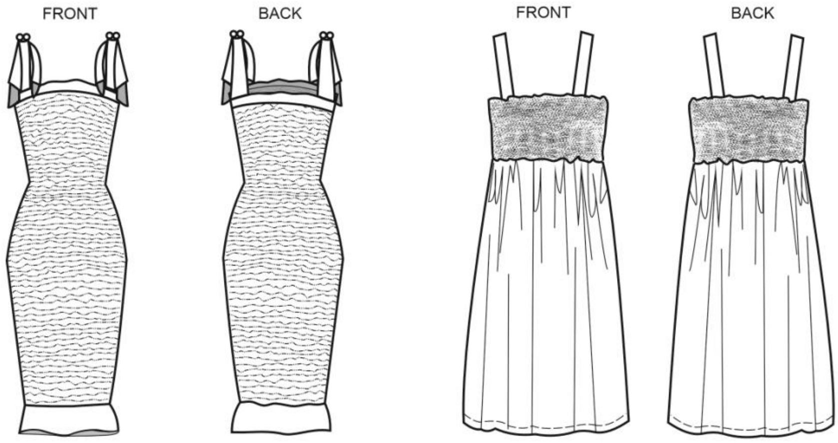



*Figure 8: Beneficial zero waste design of two dresses obtained by help of fabric shirring with elastic thread*

## CONCLUSIONS

Since low-priced man-made fibers are widely used in the textile industry and garments are mass-produced, the concept of ZWD - the maximal use of highly valuable raw materials - has lost its original idea. However, because of up normal textile wastes created by the fashion industry, the ZWD concept is getting again popular among fashion designers. The industry already now offers wide range of multi needle machines that can perform fabric shirring in high quality and efficient way. Designers should pay much more attention to the benefits of shirring as a clothing designing technique to create garment styles with reduced pre-consumer fabric waste.

## ACKNOWLEDGEMENTS

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# ENTREPRENEURSHIP IN THE TEXTILE INDUSTRY AND ITS ROLE IN DRIVING SUSTAINABLE SUPPLY CHAIN PRACTICES

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**ABSTRACT**

This paper explores the role of entrepreneurship in advancing sustainable supply chain practices within the textile industry. Entrepreneurs are leading the way by adopting innovative business models, such as circular economy practices and direct-to-consumer strategies, which prioritize sustainability and reduce environmental impact. Technological advancements, including blockchain and material science innovations, are key enablers of these sustainable practices, enhancing transparency, efficiency, and consumer trust. Effective supply chain management, supported by strategic partnerships and ethical sourcing, ensures that sustainability is maintained throughout the production and distribution processes. The paper also highlights the importance of collaboration between governments, enterprises, and consumers in promoting and sustaining these practices. Through this comprehensive approach, entrepreneurship is positioned as a driving force for systemic change, paving the way for a more sustainable textile industry.

**Key words**: Sustainable Supply Chains, Textile Industry, Entrepreneurship, Circular Economy, Technological Innovation

## INTRODUCTION

With growing environmental and social concerns worldwide, the textile sector faces pressure to become more sustainable. Entrepreneurs are particularly well placed to contribute to this transformation, because they tend to be more innovative and disruptive than traditional actors (Negrete & López, 2020). New business models, technologies and approaches can be used to embed sustainability throughout the supply chain.

Entrepreneurs are redesigning the manufacturing, distribution and consumption of textiles to incorporate circular economy principles – designing out waste and maximizing the use of materials. They are designing for the 'cradle-to-cradle' vision rather than the traditional linear 'take-make-dispose' vision. They are designing products to stay in the system for as long as possible – to be reused, recycled, or biodegraded (Hansen & Schmitt, 2021). And they are designing them, so they fit within the constraints of the environment – they are being designed for circularity. They are also appealing to an increasing number of consumers with a growing appetite for sustainability. The direct-to-consumer models are another type of innovation that can cut out greenhouse gas emissions in the supply chain, by cutting out intermediaries and the complex logistics networks that flow through them.

Nevertheless, rising consumer demand for sustainability presents new opportunities for entrepreneurs with the ability to source more expensive raw materials such as organic cotton or recycled polyester and to manage more complex global supply chains, enabling transparency and accountability. Meanwhile, new technologies such as blockchain for supplier transparency, or automation for efficiency, are equally important for the shift towards sustainability in the industry.

While the path to sustainable supply chains is certainly clear, there are many challenges specific to the textile industry. Entrepreneurs have to face high costs in sourcing green materials, as well as the logistical burden of tracking every step of the supply chain. Most forms of sustainable materials, such as organic cotton or recycled polyester, are more expensive and harder to source than their conventional counterparts (Shen et al., 2017). For small and medium-sized enterprises (SMEs), increased costs can be a significant strain, as they might not have the financial ability to absorb these costs. Furthermore, practicing sustainability across all links in the supply chain is a tall order. Even within a single country, the discrepancy between local and international standards can be dramatic. Entrepreneurs must also face the challenge of changing consumer behavior (Đorđević et al., 2011). If consumers are unwilling to pay a premium for sustainable products or lack awareness to consider how their purchasing decisions impact the environment, the task of advocating for sustainable products becomes doubly difficult. But even with these barriers, opportunities are plentiful. The shift in demand towards sustainable products creates a sizable, profitable market for businesses that can accurately position themselves as sustainable leaders. Meanwhile, companies that commit to sustainable practices can differentiate themselves by creating value. As consumers' awareness of sustainability increases, the market will reward companies that make sustainability a priority.

## INNOVATIVE BUSINESS MODELS AND THEIR CHALLENGES IN SUSTAINABLE TEXTILE SUPPLY CHAINS

Entrepreneurship in the textile sector is driving many of the innovations in the business models that support sustainability in the sector. Beyond just creating new products, entrepreneurship is actually recreating the entire business model based on textiles, fundamentally changing the way that the sector is producing, distributing, and consuming. With growing social and environmental awareness, entrepreneurs are going back to the drawing board to create new approaches to doing business that go beyond ticking the box for sustainability (Zhuravleva & Aminoff, 2021). The business drivers behind these new models are far more than just the ethical or sustainability mission; many of them are grounded in the economic advantages that can be gained through sustainable practices.

One important strand here is the move towards circular economy principles, where instead of following the traditional linear model (extracting resources to make a product, then throwing that product away). Entrepreneurs are designing products with the entire lifecycle in mind, creating textiles, for example, that can easily be recycled, upcycled or biodegraded(Koszewska, 2018). This is a great fit with consumer demand.

New business models, such as clothing rental or subscription services, reflect a shift in consumer behavior and eliminate the need for permanent purchase of fashion products, thus reducing the pressure on demand for new textiles and their associated environmental costs. In the same way, direct-to-consumer models allow companies to cut out intermediaries and lower logistics' carbon footprint (Harsanto et al., 2023). However, these examples also illustrate that although greener business models exist, it is not easy for all organizations to implement them because of high costs and complex supply chains. Small and medium-sized businesses especially benefit from this.

Making global supply chains more transparent and accountable poses a challenge but is imperative. Entrepreneurs need to invest in supplier relations and state-of-the-art tracking systems in order to meet their sustainability commitments. As more consumers show interest in sustainability, it becomes important for entrepreneurs to communicate the value of eco-friendly products, in order to overcome their sensitivity to price (Shen et al., 2017). Despite the challenges of the above-stated issues, the shift towards sustainability in consumer behaviors opens up significant opportunities for entrepreneurs in the textile industry. If this sector is to move towards a greener future, entrepreneurs will have to balance the innovation challenges with the practical challenges.

## TECHNOLOGICAL INNOVATION AND SUPPLY CHAIN MANAGEMENT IN SUSTAINABLE TEXTILE ENTREPRENEURSHIP

While innovation is not the only solution to the sustainability challenges of the textile sector, technological tools and methods are important, because the physical processes in textile production are a major contributor to unsustainable practices. It is primarily through technological innovation that entrepreneurs experiment with new ways of improving sustainability (Yang et al., 2023). The most promising developments include innovations that support a number of sustainable goals, by improving operational efficiency and transparency, by developing new materials, and above all by reducing the sector's environmental footprint.

For example, blockchain is very useful for the textile industry because it improves the traceability of each step of the supply chain and it gives the consumers who are interested in buying a specific product full transparency about all the steps involved (Saberi et al., 2019). If a brand can show that it uses sustainable materials and even the dyes are obtained sustainably from agriculture waste, which ensures good working conditions for all workers on all levels, it will distinguish itself from its competitors and the brand's success will be ensured.

Innovations in automation and manufacturing technologies have a role to play too. Automating the cutting parts of garment production ensures that excess fabric use is minimized and waste is reduced, keeping production costs down – making sustainable production more affordable. Digital printing technologies have the potential to encourage on-demand production, reducing excess inventory waste and allowing for more customized production which is also more in line with sustainability goals (Farajpour et al., 2022).

The second is material innovation: entrepreneurs are using science and technology to source bio-based fibers from renewable sources, create new materials from recycled plastics and other materials, change the texture and feel of fibers for enhanced durability, and use 3D printing to reduce textile waste and cut the use of virgin materials (Kubáč & Kodym, 2017).

The successful entrepreneurs have figured out how to integrate these technologies into their supply chains to help develop viable, attractive sustainable products. As the case studies demonstrate, technological innovation like blockchain and closed-loop systems can help provide vital impetus for sustainability, especially in terms of improving transparency and reducing waste. Even though some entrepreneurs are still grappling with the actual cost of sustainable materials, they nonetheless show how sustainable business models are viable (Rejeb et al., 2019). The fact that these entrepreneurs are embracing technology and innovation to further the cause of sustainability in the textile industry and are proving that you can make profit and be environmentally responsible at the same time, is highly encouraging.

## THEORETICAL MODEL

After analyzing the existing body of literature, a theoretical model for improving entrepreneurship in textile industry and improving sustainable supply chain practices.

For the need of entrepreneurship in textile industry, the multiple mutual interactions among its elements provide a net in sustaining the supply chain practices. The sub-elements jointly target to bigger goals of innovation, technology evolution and supply chain management in a holistic manner towards sustainability.

This means that innovative business models are fundamental to transforming the textile sector. Consistently with a circular economy logic, the recyclability and upcyclability of materials has to be factored into product and collection design, which in turn relies on the use of compatible materials. The mode of distribution plays an important role in the environmental impact of a product and a product model, and direct-to-consumer modes considerably reduce the environmental impact of distribution, which cannot be overlooked. A direct-to-consumer model also increases the efficiency of on-demand production, strengthening a natural match between supply and demand, therefore reducing excessive production on one end and excessive waste on the other.

Technological change reinforces these business models. Blockchain technology guarantees traceability of materials, making it possible to verify the provenance of materials, ensuring ethical standards right through supply chains. Increasing automation and advanced manufacturing optimizes production processes, while wastage is minimized. Energy-efficient technologies such as renewable energies keep down the greenhouse gas footprint of manufacturing, reinforcing the green credentials of other activities.

Supply chain management is crucial because it is responsible for ensuring implementation and maintenance of these sustainable practices. Good relations with trustworthy suppliers and regular audits of these businesses guarantee compliance with sustainability standards. The use of technological innovations such as blockchain ensures transparency and verifiability of sustainability claims. Working with NGOs and industrial groups not only provides credibility for the brand but also helps to build networks of information and resources. Implementing risk management strategies is essential, since these helps supply chains cope with crises and prepare for future shocks or disruptions. Finally, education about sustainability is critical for creating a culture of responsibility, which then further increases demand for sustainable products and entrenches sustainability efforts throughout the industry.

*Figure 1: Sustainable entrepreneurship in textile industry*

## SUGGESTIONS AND GUIDELINES

The developed model provided insights based on which suggestions and guidelines for sustainable entrepreneurship in textile industry are highlighted:

- Governments should enforce laws requiring disclosure of textile supply chains by companies. These companies should be obliged to make known the origins of the fibres it uses, and whether the products are ecologically friendly or not.
- Businesses should spend more on research and development for green materials and technologies: investing in low-carbon replacements for existing products and processes will have a minimal environmental impact and create a new market for green technologies.
- Governments should use financial incentives such as tax allowances or grants to encourage businesses in the supply chain to increase sustainability. These incentives would overcome obstacles for smaller companies to make the investment needed for sustainable innovation.
- Enterprises should have good relations with suppliers who have the same values as the company for sustainability and also good ethical practices. Long-term relations with responsible suppliers will secure the integrity of supply chain and prevent a wrong trade.
- By being part of clothing rental or recycling schemes, individuals reduce the amount of textile waste that ends up in landfill or in the environment while at the same time helping textile models that promote a circular economy to flourish.
- Governments not only should encourage the development of sustainability-focused public-private partnerships within their textile industry, but they also should support these partnerships in order to develop industry standards and best practices that benefit all actors.
- Working with enterprises, blockchain technology could prove highly effective in facilitating the development of product supply chains that are more transparent and traceable overall,

enabling consumers to verify claims about sustainability and ethical sourcing in a trustworthy manner to build brand loyalty.

- People can lobby for and support legislation that promotes sustainable practices throughout textile supply chains. They can meet with policymakers and support legislation that incentivises widespread sustainability throughout the textile industry.

## CONCLUSION

Entrepreneurship is a key driver in transforming the textile industry toward sustainability. Through innovative business models like circular economy principles and direct-to-consumer strategies, entrepreneurs are reshaping traditional practices to reduce environmental impact and uphold ethical standards. Technological advancements, including blockchain for supply chain transparency and material science innovations, are critical tools that enable these sustainable models. The use of these technologies doesn't just enhance operational efficiency but also fosters consumer confidence through increased transparency.

Good supply chain management, with long-term partnerships and ethical engagement with suppliers, ensures that this sustainability ethos is embedded at every stage of textile production and distribution. Working with governments, NGOs and industry bodies, these practices can be stabilized and strengthened. Consumer awareness and engagement are key, too: well-informed consumers can make the difference between a business expanding its eco-credentials or backing away from them because they are not profitable.

Their convergence represents a whole-of-system perspective that shows how entrepreneurial forces can drive transformative change within the textile sector. It demonstrates how the role of governments and enterprises is crucial to creating the right conditions that allow sustainable practices to become the norm. Such a whole-of-system approach positions the textile sector well to address both the environmental and the social challenges that it faces and will likely continue to face in the future.

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# INVESTIGATION OF DIMENSIONAL STABILITY OF ARTIFICIAL PINAPLE AND CORCK LEATHER

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## ABSTRACT

In recent years, significant changes have occurred in the textile and clothing industry, driven by the need for sustainable development and production. The textile industry is responsible for approximately 10% of global greenhouse gas emissions. As a result, there is growing interest in ecologically sustainable materials, such as those derived from plant-based sources like fruit waste and other plant parts, which offer an alternative to fossil-fuel-based textiles. This study examines the dimensional stability behavior of three types of sustainable textile materials used as alternatives to animal leather. These materials include non-woven fabrics made from pineapple and cork. Three samples of non-woven vegan leathers, differing in thickness and surface mass, were analyzed. The materials were subjected to three cycles of home washing and drying. Changes in dimensions were measured after each cycle and expressed as a percentage of the initial size. The experimental results indicate that shrinkage was highest after the first wash and dry cycle, with the shrinkage being more pronounced in the vertical direction. Cork exhibited a slightly different behavior compared to the pineapple-based material. These findings provide insight into the shrinkage behavior of these alternative materials and their potential for use in sustainable fashion applications.

**Keywords**: Circular economy, sustainable fashion, eco-friendly materials, pineapple leather, cork leather, shrinkage

## INTRODUCTION

**Sustainable development** is an evolving process that continually adapts to changing goals and priorities, aiming to achieve sustainability in all aspects of human life. The principles of sustainability are rooted in three core dimensions, which are interconnected and evaluated as a whole (1,2,). These principles form the foundation for individual awareness and action toward sustainability:

- **Ecological**
- **Social**
- **Economic** (3)

In the fashion and textile industry, sustainable practices often aim to implement the circular economy model in business strategies. The circular economy is a framework designed to eliminate waste through the continual reuse of products and materials. Its core principles—reduce, reuse, and recycle—focus on minimizing waste and optimizing the lifecycle of resources. A key aspect of the circular economy is the experimentation with alternative materials, which plays a crucial role in reducing the environmental impact of the industry.

During the past almost half a century, the way of production and consumption of fashion has changed drastically. The growth of the world's population and its needs caused a three-fold increase in the volume of textile production, which resulted in the phenomenon of "fast fashion". Excessive seasonal collections, low prices, discounts and promotional campaigns, the ease of one-click online shopping, the influence of social media, all these factors have led individual consumption to the point that as much as 85% of textile articles (5.8 million tons) are thrown into landfills every year. and wild landfills, instead of being handed over to recycling centers, and further degraded back into the environment. Per capita clothing purchases are increasing rapidly and are now worth 13 kilograms per year in most countries. (4) Only 1% of the material used to produce clothing is recycled. (5) The textile industry is estimated to be the second largest polluter of clean water in the world, where every washing cycle of synthetic textiles releases half a million tons of microplastics, which is equivalent to 50 billion plastic bottles. (1)(4) All these negative consequences have led to the increasing use of natural, biodegradable materials.

Natural fibers such as cotton, wool, silk and flax have long been known to the textile industry, but textile materials obtained from by-products after processing fruits, oranges, pineapples, sugar canes, mangoes, bananas represent environmentally friendly and sustainable textile materials that represent a relatively new trend. For this reason, in this work, the dimensional stability of non-woven textile materials used as an alternative to natural and synthetic leather, obtained from pineapple and cork, was examined and analyzed. By examining the behavior of the materials during washing, it can be determined whether and in what way they satisfy the usage characteristics and whether they can be used as a good substitute for synthetic and natural leather.

## ANIMAL LEATHER AND ITS ALTERNATIVES

Today's consumers are increasingly concerned with the origin and composition of their clothing, prompting brands to adopt new business models that integrate ethics, aesthetics, and innovation. A prime example of such innovation is the development of biodegradable textile materials derived from fruit (1)(5)(6).

In contrast, traditional leather, sourced from cattle (cows, sheep, goats), is tanned using harmful chemicals, including chromium, lead, arsenic, and other heavy metals. These substances not only pose risks to the health of workers in the leather industry but also have adverse environmental impacts (7). Furthermore, animal skin is typically limited to a few colors—black, brown, and white—and is characterized by high porosity, air permeability through the pores, and a tendency to easily absorb liquids and odors. Home washing of animal leather is not recommended, as it requires specialized care. Additionally, the ends of natural leather are often ragged and stiff, and when pressure is applied to its surface, it forms furrows similar to a spider’s web. With proper maintenance, natural leather can last for decades, developing a patina that adds to its visual appeal over time (8).

Synthetic leather is available in a wide range of colors, and the pores on its surface are evenly distributed. The edges are uniform, clean, and consistent. It is thinner, lighter, waterproof, with a lifespan of about one year, and its wear is evident through cracking and peeling of the surface. Artificial materials do not allow the skin to breathe, making garments less comfortable to wear. Infinitum Global analysts predict that the demand for vegan leather will increase to 49.90% by 2025 (8). Vegan leather is three times cheaper than animal leather, which attracts a large number of buyers, particularly in the middle class (9).

There are many sustainable brands: Corkor and Jentil, which use cork in the production of leather goods, and sneakers made from pineapple fibers, an ethical product by Nae Vegan Shoes. Meanwhile, the brand H&M incorporates Piñatex in its Conscious Exclusive collection (9).

Therefore, sustainability can be defined as the way natural systems function, remaining diverse and producing everything necessary to stay in balance with nature, where human creativity enables all forms of waste to be reborn in new forms through design (6)(10).

## ARTIFICIAL PINEAPPLE LEATHER

Textile materials made from pineapple, known as **Piñatex**, were developed and successfully introduced to the market by the Spanish company **Ananas Anam**. These materials serve as a natural alternative to leather (3,4). Piñatex is produced from fibers extracted from discarded pineapple leaves, utilizing a byproduct of the existing pineapple harvest, thereby eliminating the need for additional ecological resources in raw material production (4).

Pineapple fibers, which are ideal for textile production, are typically cultivated in India and the Philippines. Leaves from plants that are 1 to 1.5 years old are often selected for fiber extraction, as the fibers are easier to separate from the leaf tissue at this stage. The method of fiber extraction, chosen after the leaves are selected, plays a significant role in determining the quality of the fibers. (3)

## CORCK LEATHER

Cork leather is a sustainable, vegan and environmentally friendly solution, but also a renewable alternative to animal skin. (12) Cork leather is a material made from the outer bark of the cork oak (Quercus suber L.), which has been collected from this plant species for more than five millennia. (13) Cork oak is native to the western Mediterranean basin, with the largest cork production areas in Portugal (Alentejo region) and Spain, followed by Italy, France and North Africa (Algeria, Morocco and Tunisia). The trees of this plant species are of medium height (15–20 m), with a wide canopy. (14)
Cork textile material has a light structure, very soft to the touch, visually attractive, refined with natural texture and unique patterns. (12) It is hydrophobic and resistant to stains, hypoallergenic, where thermal degradation begins only at 200°C, burns without flame and without the release of toxic gases. It repels dust, dirt and grease, which guarantees that cork leather goods will stay clean. The claim that half the volume of cork is air makes products made from it much lighter than articles of animal origin (density of cork = 160-260 kg/m3). (13)(17)(18)

## EXEPERIMENTAL PART

### Materials and methods

In this study, three non-woven textile materials were used: Piñatex® Metallic Wrinkled Black, Piñatex® Performance Polar White and Cork, the characteristics of which are shown in Table 1. The thickness of the samples was determined by an apparatus - a thickness gauge, made of two parallel metal plates, between of which the material is placed. The pressure of the upper plate on the tested textile is 50 cN/cm 2. (20) This parameter of the textile material was measured in accordance with the relevant standard IS0 9073-2:1995(21)(22)(23)(24). The results of material thickness measurements are shown in Table 2.

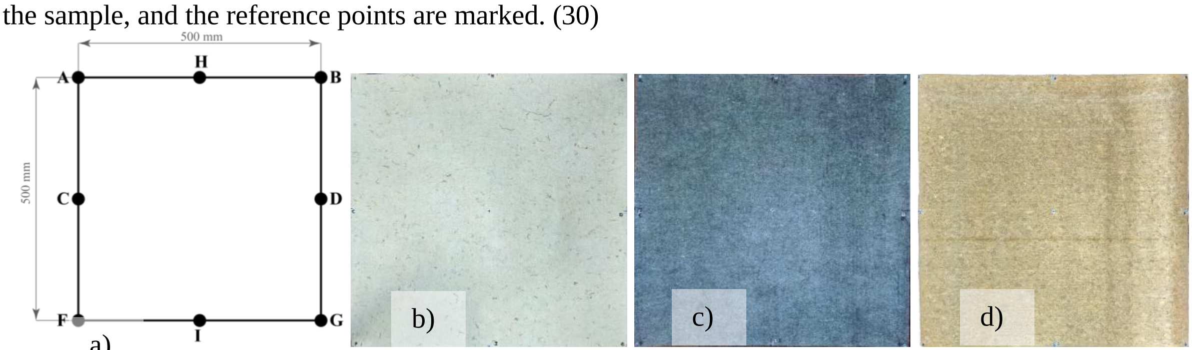
Table 1 shows the characteristics of the samples used in the test work. Pineapple 1 represents a sample of the material obtained from 72% pineapple fibers, 18% polylactic acid and 10% polyurethane. Pineapple 2 is a sample obtained from 46% pineapple fibers, 42% polyurethane and 12% polylactic acid. Cork 1 is a sample obtained from 100% cork.

*Table 1. Characteristics of the samples*

| | **Pinaple 1** | **Pinaple 2** | **Corck** |
|---|---|---|---|
| Composition | 72% PALF<br>18% PLA<br>10% PU | 46% PALF<br>42% PU<br>12% PLA | 100% corck |
| Weight [$g/m^2$] | ≈ 537 | ≈ 642 | ≈ 152 |
| Thickness [*mm*] | 1,169 | 1,754 | 1,178 |

Dimensional stability of a textile material is a measure of the linear change in dimensions that occurred as a result of submerging the textile material in a liquid, i.e. water. (28) Products with good dimensional stability can be called those whose initial shape remains unchanged during several washing and wearing cycles, i.e. no shrinkage or expansion occurred. For textile products, it is of great importance to determine the linear dimensions not only immediately after production, but it is necessary to define the change in dimensions that may occur during the washing or ironing process, as well as during use. (29)

The dimensional stability of the previously mentioned leather alternatives was tested according to the guidelines of the SRPS F.S2.020 standard, i.e. ISO 3759:2011. Material sampling was performed according to the ISO 3759:2011 standard, where each sample is a 500x500 mm square, the edges of which are cut parallel to the length and width of the material. The sample is placed on a smooth, flat surface, the wrinkled places are removed without stretching the material. The ruler is placed on the surface avoiding distortions of the sample, and the reference points are marked. (30)




a)*Figure 1. Marking of reference points: a) Presentation of the marking of reference points; b) Pineapple 1 after washing, c) pineapple 2 after washing and d) float after washing*

The washing and drying of the samples were carried out in accordance with the standard prescribed test procedures for washing and drying in home conditions, i.e. according to the ISO 6330:2012 standard. The textile materials were washed in a Gorenje WA 583 household machine, using the program for wool and very sensitive fabrics, in a high level of water with gentle rubbing, at a temperature of 40°C, for 30 minutes, with a minimum number of drum revolutions per minute - up to 500 m-1, where the program ends with a two-minute spin, with the addition of 20 ml of Merix Orhideja gel liquid detergent with optical brighteners and enzymes, with water hardness ≈ 6.8 °dH (soft water→0-7 °dH = 0-1.3

mmol/l). After removing the samples from the machine, they were placed on a flat and smooth surface where they were dried at room temperature in the time range of 5-20 h.

b) c) d)

Figure 2. Presentation of the process of washing and drying the material: b) Pineapple 1 c) pineapple 2, d) cork

The measurements of each washed and dried sample were taken along the width and length of the material. Dimensional stability in both directions was calculated after each washing and drying cycle, where it was evaluated as expansion (+) or shrinkage (-). (28) The original dimensions of the samples before testing (L0) are 500x500 mm according to the ISO 3759:2011 standard. The samples were measured a second time after washing, in a wet state (L1), then they were placed on a flat surface where they were dried at room temperature, which was followed by another measurement (L2). (29) The measurement was carried out: horizontally → AB, CD, FG and vertically → AF, HI, BG. After these measurements, the samples were subjected to washing two more times. Changes in dimensions are shown in Tables 4, 5 and 6.

***Table** 3. Presentation of the change in the dimensions of the cork material after three cycles of washing and drying in home conditions. L0 initial dimension of the sample before washing, L1 length of the sample after the first wash, L2 dimension of the material after the second wash.*

| | Corck1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | First wash | | | Second wash | | | Third wash | | |
| | $L_0$ [mm] | $L_1$ [mm] | $L_2$ [mm] | $L_0$ [mm] | $L_1$ [mm] | $L_2$ [mm] | $L_0$ [mm] | $L_1$ [mm] | $L_2$ [mm] |
| AB | 500 | 507 | 501,5 | 500 | 507 | 500 | 500 | 507 | 500 |
| CD | 500 | 508 | 502 | 500 | 507 | 500 | 500 | 507 | 500 |
| FG | 500 | 505 | 502 | 500 | 507 | 500 | 500 | 506 | 500 |
| $\bar{x}$ (AB, CD, FG) | **500** | **506,667** | **501,833** | **500** | **507** | **500** | **500** | **506,667** | **500** |
| AF | 500 | 499 | 497 | 500 | 497 | 495 | 500 | 496,5 | 494 |
| HI | 500 | 499 | 496 | 500 | 497 | 495 | 500 | 496 | 494,5 |
| BG | 500 | 500 | 499 | 500 | 500 | 496 | 500 | 497 | 496 |
| $\bar{x}$ (AF, HI, BG) | **500** | **499,333** | **497,333** | **500** | **498** | **495,333** | **500** | **496,5** | **494,833** |

***Table** 4. changes in dimensions of sample Pineapple 1 after three cycles of washing and drying in home conditions. L0 initial dimension of the sample before washing, L1 length of the sample after the first wash, L2 dimension of the material after the second wash.*

| | Pinaple 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | First wash | | | Second wash | | | Third wash | | |
| | $L_0$ [mm] | $L_1$ [mm] | $L_2$ [mm] | $L_0$ [mm] | $L_1$ [mm] | $L_2$ [mm] | $L_0$ [mm] | $L_1$ [mm] | $L_2$ [mm] |
| AB | 500 | 499 | 496 | 500 | 498 | 494 | 500 | 496 | 494 |
| CD | 500 | 500 | 497 | 500 | 497,5 | 494 | 500 | 497,5 | 494 |
| FG | 500 | 499 | 496 | 500 | 498 | 494 | 500 | 495 | 493,5 |
| $\bar{x}$ (AB, CD, FG) | **500** | **499,333** | **496,333** | **500** | **497,833** | **494** | **500** | **496,167** | **493,833** |
| AF | 500 | 495 | 492 | 500 | 495 | 492 | 500 | 494 | 491 |
| HI | 500 | 496 | 493 | 500 | 496 | 492,5 | 500 | 494 | 491,5 |
| BG | 500 | 497 | 495 | 500 | 496 | 493 | 500 | 495 | 492,5 |
| $\bar{x}$ (AF, HI, BG) | **500** | **496** | **493,333** | **500** | **495,667** | **492,5** | **500** | **494,333** | **491,667** |

*T**able** 6changes in dimensions of sample Ananas 2 after three cycles of washing and drying in home conditions. L0 initial dimension of the sample before washing, L1 length of the sample after the first wash, L2 dimension of the material after the second wash.*

(Ctrl)

| | Ananas 2 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | First wash | | | Second wash | | | Third wash | | |
| | $L_0$ [mm] | $L_1$ [mm] | $L_2$ [mm] | $L_0$ [mm] | $L_1$ [mm] | $L_2$ [mm] | $L_0$ [mm] | $L_1$ [mm] | $L_2$ [mm] |
| AB | 500 | 498 | 498 | 500 | 498 | 496 | 500 | 496 | 496 |
| CD | 500 | 498 | 498 | 500 | 498 | 497 | 500 | 497 | 497 |
| FG | 500 | 498 | 498 | 500 | 498 | 497 | 500 | 495,5 | 495,5 |
| $\bar{x}$ (AB, CD, FG) | **500** | **498** | **498** | **500** | **498** | **496,667** | **500** | **496,167** | **496,167** |
| AF | 500 | 498 | 498 | 500 | 500 | 497 | 500 | 497 | 496 |
| HI | 500 | 500 | 500 | 500 | 500 | 497,5 | 500 | 496 | 496 |
| BG | 500 | 500 | 499 | 500 | 500 | 498 | 500 | 496 | 496 |
| $\bar{x}$ (AF, HI, BG) | **500** | **499,333** | **499** | **500** | **500** | **497,5** | **500** | **496,333** | **496** |

Shrinkage represents a change in the dimensions of the test tube, i.e. its surface, under the influence of moisture, heat and washing or chemical cleaning agents. Shrinkage of nonwoven textile materials is calculated in both directions, widthwise and lengthwise, from the equation:

$$S_o = \frac{\check{S}_s - \check{S}_i}{\check{S}_i} \cdot 100[\%] \quad (2)$$

Where is:
$S_o$ – collection of materials [%],
$\check{S}_i$ – tube size before treatment (measured original dimensions) [mm]
$\check{S}_s$ - dimension of the test tube after the test (average value of the samples horizontally/vertically) [mm]. (30)

*Table 7. Horizontal and vertical shrinkage of the examined materials through three cycles of washing and drying*

| | Change in dimensions horizontally [%] | Vertical dimension change [%] | Change in dimensions horizontally [%] | Vertical dimension change [%] |
|---|---|---|---|---|
| | Originalne dimenzije→Mokro stanje | | Mokro stanje→Suvo stanje | |
| Corck, first wash | +1,333 | -0,133 | -0,954 | -0,401 |
| Corck, second wash | +1,030 | +0,134 | -1,381 | -0,536 |
| Corck, third wash | +1,333 | +0,236 | -1,316 | -0,336 |
| Pinaple 1, first wash | -0,133 | -0,800 | -0,601 | -0,538 |
| Pinaple 1, second wash | +0,302 | +0,473 | -0,770 | -0,639 |
| Pinaple 1, third wash | +0,439 | +0,372 | -0,470 | -0,539 |
| Pinaple 2, first wash | -0,400 | -0,133 | 0,000 | -0,067 |
| Pinaple 2, second wash | 0,000 | +0,200 | -0,268 | -0,500 |
| Pinaple 2, third wash | -0,101 | -0,235 | 0,000 | -0,067 |

## RESULTS AND DISCUSSION

Two samples of pineapple skin and one of cork were subjected to washing and drying in three cycles, consecutively, under home conditions. In the tested cork leather, during the first washing and drying, a slight increase in the dimensions of the sampled material in width (+0.367 %), but also shrinkage in the direction of the ventricle (-0.533 %) was recorded. In the next two cycles of washing and drying in ambient conditions, there were no changes in the dimensions of the material horizontally compared to the original dimensions, while the shrinkage of the material occurred vertically in a total percentage of about 1%. In the sampled pineapple skins, shrinkage was recorded in both the horizontal and vertical directions during all three washing cycles, where the shrinkage is greatest after the first wash, in subsequent cycles that percentage decreases. The obtained test results are shown in Graph 2. The percentage reduction in dimensions horizontally ranges from 0.768% for Pineapple 2 to 1.237% for Pineapple 1, while the vertical shrinkage is in the range of 0.802-1.671%.

## CONCLUSION

The aim of this work was to examine the dimensional stability of sustainable animal skin substitutes through three cycles of washing and drying in home conditions. The tests were performed according to the standards IS0 9073-2:1995, ISO 3759:2011 and ISO 6330:2012. where dimensional changes were measured immediately after the end of each cycle. In this study, three nonwoven textile materials, two pineapple skins and one cork skin, showed different behavior during three washing and drying cycles. Dimensional shrinkage is greatest after the first washing and drying, with the exception of cork, and the value of shrinkage is higher vertically. The estimated values of shrinkage in the vertical direction are between 0.80 - 1.67 %, and in the horizontal direction in the range of about 0.77 - 1.24 %. Only in cork leather there was stagnation, i.e. negligible expansion (0.001%). Based on the experimental procedures performed, considering the rate of shrinkage/elongation no higher than about 1.7%, we can conclude that the tested materials are of satisfactory dimensional stability, suitable for making accessories (bags, wallets), shoes, clothing or accessories.
Scientists, people in the production sector, entrepreneurs, but also end consumers - all have a capital role in jointly opposing the destructive effects of textile industry pollution, first of all by changing the attitude and making each link in the "chain" aware of the concept of clothing and fashion as something current, which will be rejected, and in future times will pretend to occupy every corner of the planet, rising above us like some kind of "mountain". A change of the whole system is needed, ensuring a circular fiber industry. Therefore, textiles made from plant waste elements are now being marketed as one of the potential solutions

that will initiate the endless areas choked with clothing waste items to become just a memory, and today's moment marks the beginning of ecological and social changes in the textile field. (4)

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# MULTIFUNCTIONAL AND MODULAR APPROACHES IN A SUSTAINABLE COLLECTION OF CLOTHING ITEMS

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**ABSTRACT**

With the advent of fast fashion, which relies on cheap production, frequent consumption and short-term use of garments, the fashion industry continues to grow at an extraordinary rate. However, this rapid growth has contributed to the climate and environmental crisis in the sense that every production process, from the production of fibers to the transportation of finished garments, has a negative impact on the environment. Issues such as textile material and clothing recycling, as well as sustainable clothing production methods such as clothing upcycling are becoming topics of public debate. Consequently, this study first of all provides a comprehensive analysis of the environmental impact of the fashion industry, and provides an example of a solution using sustainable practices. The study will firstly examine resource consumption and waste generation in every part of the production process, then it will examine the methods of multi-functionality and modularity in the upcycling production of garments as an approach to sustainable practices for the fashion industry.
This study highlights the need for the fashion industry to turn towards sustainability. Highlighting the impact of the fashion industry on the environment, it represents a step for innovative methods of designing and making clothing.

**Key words**: Fashion industry, fast fashion, recycling, modularity, multifunctionality

## INTRODUCTION

The fashion industry is a dynamic force that shapes consumer trends, which is evident by the very emergence of fast fashion, which relies on cheap production, frequent consumption and short-term use of clothing items. Consequently, the fashion industry has significantly contributed to the environmental crisis. Environmental pollution is present in every step of the production process, starting from the production of fibers, all the way to the transportation of finished garments. The very production of textile fibers such as cotton has led to excessive extraction of water for the irrigation process, which has led to stress on the local ecosystems of countries and water shortages. In addition, the consequence of leather production has led to deforestation, which has also damaged ecosystems and biodiversity. Various textile processing processes that use harmful chemicals have led to a decrease in biodiversity, soil fertility and disruption of biological processes. It is also important to mention that the textile industry produces huge amounts of waste, which are divided into pre-production waste and post-production waste. All waste ends up in landfills, however many materials, such as synthetic materials, need a long period of time to decompose which also contributes to pollution, while the recycling rate is still very low and is used for less valuable applications such as insulation materials, wiping cloths and the like . Based on the above information, both production processes and consumption attitudes must change. First of all, it is necessary to conduct more research on upcycling approaches for the production of materials, as well as on the processes of construction, design and production of garments.

This paper primarily examines the negative impact of the fashion industry on the environment, and gives an example of the production of a collection of clothing items using upcycling methods, multifunctionality and modular design in order to create innovative sustainable solutions.

## CONTRIBUTION OF THE FASHION INDUSTRY TO THE ENVIRONMENTAL CRISIS

The fashion industry, a dynamic and influential global force, has significant power in shaping consumer trends. However, its extraordinary growth comes at a significant cost to the environment, contributing significantly to the climate and environmental crisis (Singh S. Bansal J., 2024). The fashion industry is the second largest industrial polluter after aviation, accounting for up to 10% of global pollution. However, despite its widely publicized environmental impacts, the industry continues to grow, in part due to the rise of fast fashion, which relies on cheap production, frequent consumption and short-term use of garments. Clothing production is mainly located in the global south, design processes are carried out in the global north, often in the EU or the USA, where the main offices of the brands are. Distance makes it difficult to avoid mistakes during production planning, which causes unnecessary waste before consumption from production. Clothing is traditionally transported by container boats, but increasing quantities are sent by air freight to save time, especially when shopping online. Air cargo has a significantly greater environmental impact, as it is estimated that shifting just 1% of clothing transport from ship to air cargo could result in a 35% increase in carbon emissions. At the end of their life, many garments are incinerated or transported to landfills or developing countries, often by ship to Africa, and few are recycled. At each stage of the supply chain mentioned above, the fashion industry has an impact on the environment. For example, current textile production uses about 44 trillion liters of water per year for irrigation (or about 3% of global irrigation water use), of which 95% is associated with cotton production. (Niinimäki K. et al., 2020). Excessive extraction of water for irrigation processes has not only strained local ecosystems but also contributed to water shortages in affected areas. Furthermore, agricultural practices in the production of leather, another significant fabric used in the fashion industry, have also been scrutinized for their environmental impact. Raising cattle for leather production requires vast amounts of land, leading to deforestation and habitat destruction. Moreover, leather production involves the use of harmful chemicals, such as tannery waste, which can damage water bodies. Industrial dyes and synthetic fibers are another significant contributor to pollution in the fashion industry. In addition, the apparel and textile industry is known to contribute to environmental degradation, including greenhouse gas emissions and the generation of wastewater and solid waste at various stages of production and extended supply chains. (Singh S. Bansal J., 2024). Heavy use of agrochemicals can cause nausea, diarrhea, cancer and respiratory diseases, and acute pesticide poisoning is responsible for nearly 1,000 deaths a day and affects neurological and reproductive problems. In the environment, agrochemicals are leached into the soil, where they cause a decrease in biodiversity and soil fertility, interrupt biological processes and destroy microorganisms, plants and insects (Niinimäki K. et al., 2020). Another negative impact of the textile industry is the textile waste that was created as a result of increased production and consumption. We distinguish between two types of waste, which are pre-consumer fashion waste, also called production waste, which occurs during the production of textiles and clothing, and includes waste from fibers, yarns and fabrics, the last of which is the biggest waste of resources. One study estimated that 15% of the fabric used in the production of garments is wasted. The second form is post-production waste, comprising clothing discarded by consumers, including nearly 60% of the approximately 150 billion garments produced worldwide in 2012 that were discarded within a few years of production. (Niinimäki K. et al., 2020). Landfills are the main option for waste disposal in modern times. However, some non-biodegradable materials in clothing, such as polyester fibers, take up to 200 years to decompose, and 72% of clothing requires this material. Thus, it can impose irreversible consequences on the soil. The decomposition of these substances releases toxic greenhouse gases, which contribute to direct or indirect pollution, which also means that the textile industry must properly manage waste (Fang B., 2023). Despite high waste, textile recycling rates are still low — only 15% of post-consumer textile waste was collected separately for recycling purposes in 2015. Most recycled textiles (6.4 million tonnes) were recycled into other, less valuable applications, such as are insulating materials, cloths for wiping and stuffing the mattress. In essence, the current business logic in the fashion sector is based on ever-increasing production and sales, rapid production, low product quality and short product life cycles. Therefore, both production processes and consumption attitudes must change. However, this requires the participation of all stakeholders: the textile industry to invest in clean technology, fashion companies to build new business models, consumers to change their spending habits and policy makers to modify laws and global business rules (Niinimäki K. et al. , 2020). It is crucial to implement environmentally friendly technologies and practices such as recycling, upcycling, multi-functional or modular approach to garment production.

**Methods used in designing a sustainable collection**

First of all, this collection was created by designing technical drawings using Adobe Illustrator. Sustainable development requires radical changes in the way it is designed, produced, consumed. These changes will not only be technical, but also social and ethical. However, making fashion sustainable means considering more than style, quality and price. Therefore, it is important that when teaching design development, the benefits of sustainable business are understood starting from the concept development level, thus extending the design aesthetics and functionality of the product. The goal of design methods should be to gain key insights or unique essential truths that result in more holistic solutions (Dr. Sharda N. L., et al, 2012). Taking these conclusions into account, the collection was designed following the methods of using upcycling methods when choosing the textile material from which the collection should be made. In the case of this collection, the primary material for making would be fabrics that must be breathable and waterproof. Currently, there are three ways to make a breathable waterproof fabric which includes the use of high density fabrics, coated fabrics and laminated fabrics (İnovenso Teknoloji Ltd.Şti, Waleedi M, 2023). This collection relies on laminated fabrics that can provide all the above characteristics and are shown in the specification together with the technical drawings in figure 3 of the paper. These fabrics are made of three layers: the first is the inner layer of the substrate, the second layer with a porous/fibrous membrane that acts as a barrier to larger molecules (vapors) and allows smaller molecules to pass through (air), and the third outer layer of waterproof fabric prevents any water vapor to pass from the outside, such as in the form of rain, snow or wind and let the vapors permeate the interior and leave the fabric (İnovenso Teknoloji Ltd.Şti, Waleedi M, 2023). The second type of fabric used by the collection represents the first recurring element of the collection, namely used blankets. The other three elements of the collection are related to the methods of construction of the garments in the collection, namely the methods of modular design of garments as well as the methods of multifunctionality of the garment. The principle of modularity of this collection is shown schematically in the example shown in Figure 1.

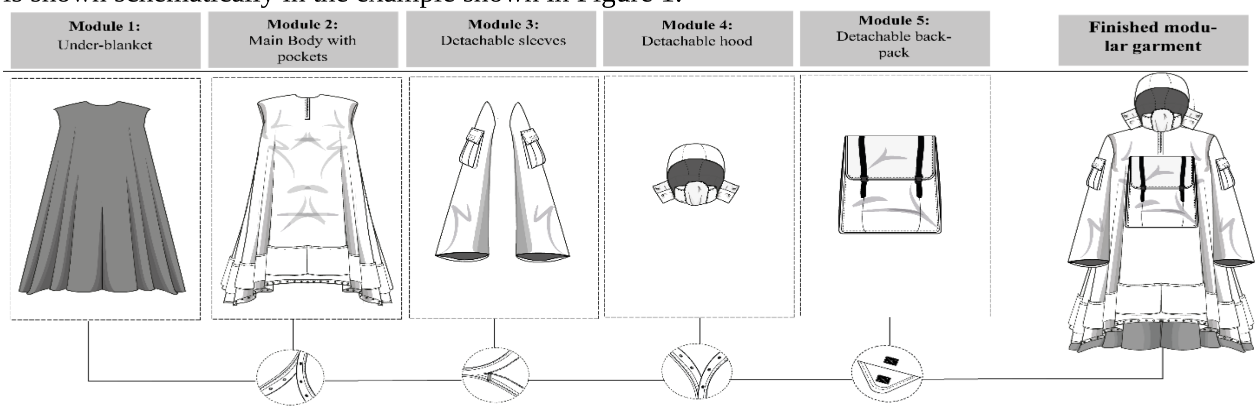


*Figure 11 An example of a modular design from a collection composed of five models with corresponding fastening forms*

It can be said that modular garments are not complete garments, but a set of modules that can be assembled and disassembled (Zang X. et al, 2024). Making a garment with ready-made components that are easily detached will give the user more options in how it can be put together, resulting in the feeling of more garments without actually being manufactured as much. The wearer can also modify the styling, fit and silhouette according to their own preference or according to the latest trend which will lead to reduced shopping (Dr. Sharda N. L.,et al, 2012). As shown in figure 1, the garment from the collection is made of five modules, the first of which is the used blanket, followed by the main body of the garment, sleeves, hood, and backpack as the fifth module. The scheme also shows the corresponding fastening, such as the dricker on the children (module 1), the main body (module 2) and the hood (module 4). In addition, a zipper is used to fasten the sleeves (module 4) and a Velcro strap is used to fasten the backpack (module 5).

Another element of the collection is the use of the multi-functionality method. The multifunctionality of garments can be defined as the creation of garments that do more with less. Multifunctional garments (also called convertibles or transformers) are garments that can be worn in multiple ways or serve multiple purposes. (Dr. Sharda N. L., et al, 2012) An example of the multifunctionality method is shown in figure 2.

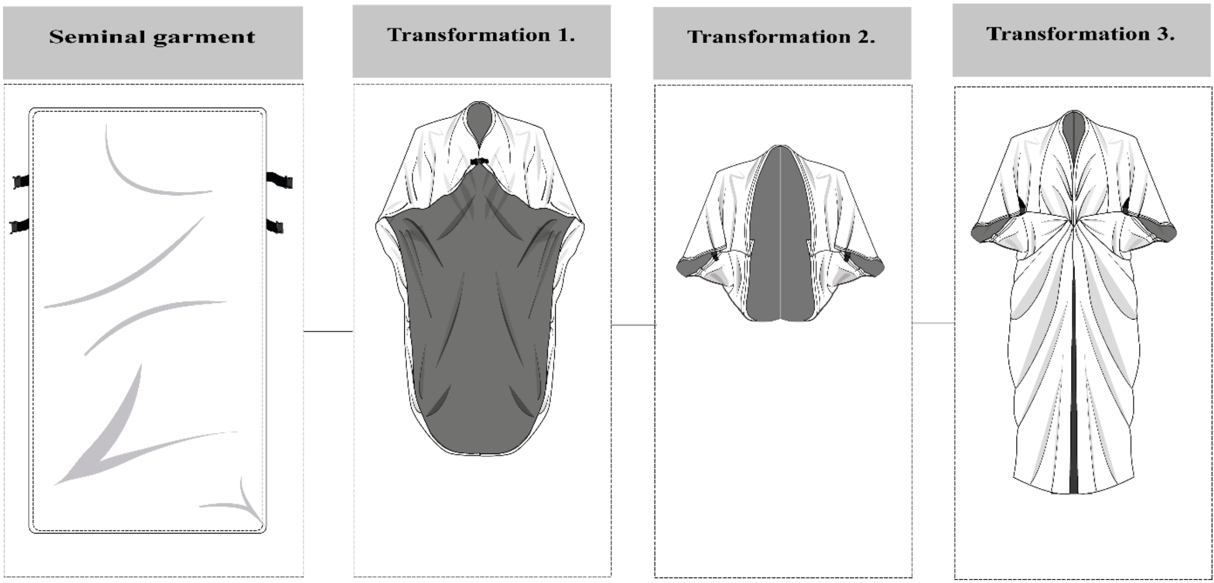


*Figure 12 An example of the multifunctionality of a garment from the collection*

The original intention of this example from the collection is to be a cover blanket, however by using a double-faced fabric (one side blanket, the other side waterproof) and the positioning of the side release buckles and dricker, this blanket is transformed into three different forms of outdoor outerwear. . In addition to the transformation of the garments, the addition of elements such as pockets, sewn-on bags, backpacks and detachable blankets were used so that the garments in the collection could serve multiple functions from different outdoor activities to storage or transportation.

**Overview of the final collection**

The final technical drawings of the complete collection can be seen in figure 3. This collection is composed of ten technical drawings of garments. The collection primarily contains three recurring elements, the first of which is the use of used blankets that can be seen in every model. The second element is directly related to the first, which is modularity. In the sense that the blankets on the models are detachable from the main garment with side sliders or drickers, as are the sleeves separable with zips or the hood separable with drickers. Thanks to the use of modularity methods, these ten items of clothing can be modified according to the wearer's wishes, thus obtaining a completely different item of clothing. In addition, due to the use of the principle of modularity, it is directly possible for the garment to have different styles as well as different purposes, which actually leads to the third element of multi-functionality. In this collection, multi-functionality is connected with detachable versions of bags and backpacks thanks to which the garment can be used to transport things without carrying excessive luggage. In addition, because of the used blankets and other mentioned elements, they contribute to the fact that the garment can be used in various outdoor activities, such as camping or hiking..

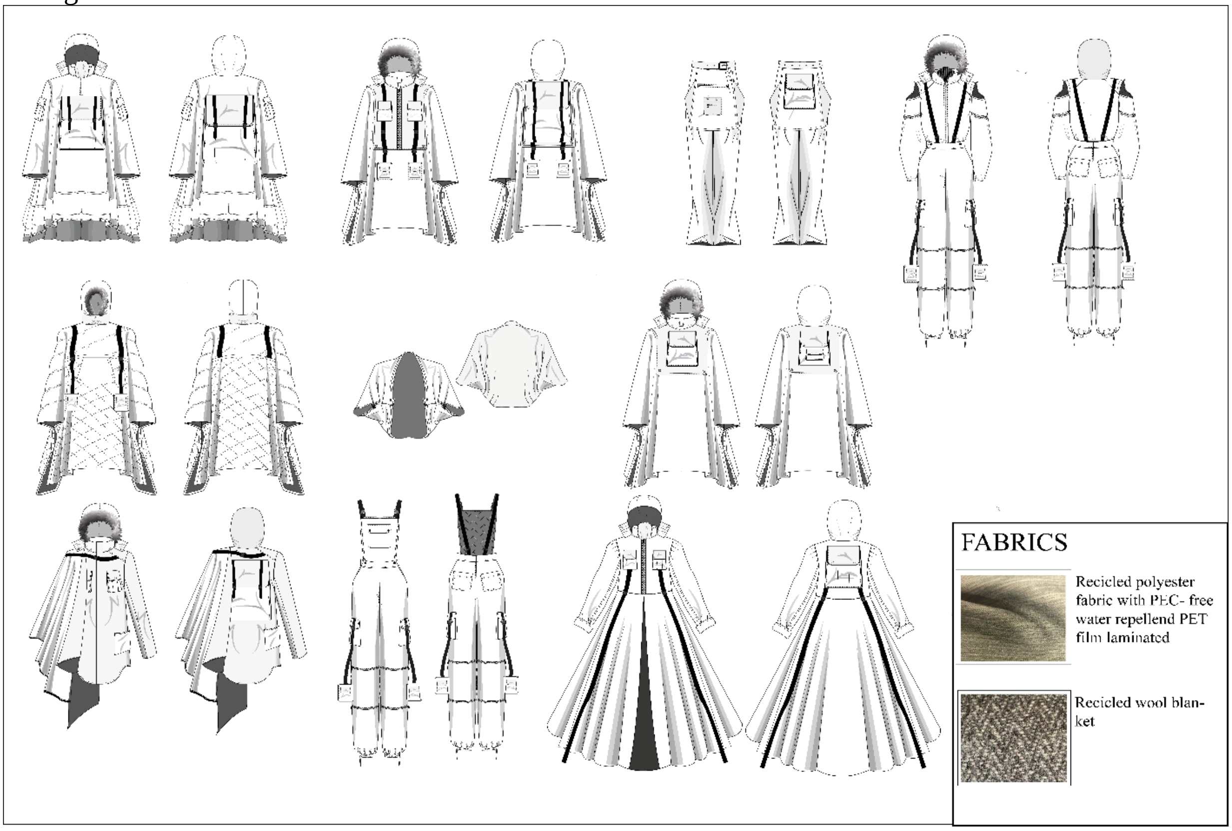


*Figure 13 A collection of multifunctional modular garments*

The design of this collection is also gender-neutral and adapts to the body difference and size between women and men through a construction predominantly based on square shapes and other semi-structural adjustments. The material from which the collection is made also provides protection against various influences, which makes these items ideal for various outdoor activities. Also thanks to the use of modularity methods all the blankets are detachable which allows these garments to be worn in any season be it winter, spring, summer or autumn.

**Discussion**

For contemporary designers, finding a new way between innovation and sustainable development is inevitable (Tang Q., 2022). Different forms of transformable clothing obtained by implementing the methods of multi-functionality and modularity bring new insights into solving sustainability problems in clothing design, as well as introduce new ideas to satisfy the wishes and needs of consumers. Incorporating modularity technology to produce mass customized clothing, a single fabric can be varied in styles in terms of silhouette, style and functionality. Constructing a garment with ready-made components that are easy to separate gives the user more options in how it can be put together, resulting in the feeling of more garments without actually producing as much. The wearer can also modify the styling, fit and silhouette according to their own preference or according to the latest trend which will lead to reduced shopping (Dr. Sharda N. L.,et al, 2012).

## CONCLUSION

This paper provides an analysis of the ways in which clothing production in the fashion industry affects the environment, and provides sustainable solutions. Making fashion sustainable means taking into account more than style, quality and price, and it is necessary to implement technical, social and ethical changes in the way it is designed, produced, consumed. Methods of recycling textile materials, modular design and multifunctionality of clothing items represent steps towards innovative solutions in construction, design and production that take care of environmental protection. Incorporating modularity and multi-functionality technology to produce mass customized clothing, one garment or even one fabric meets different needs in terms of style, functionality or silhouette. Making multi-purpose garments with ready-made components that can be easily separated provides different assembly options at will, leading to the feeling of more different garments without actually producing as many.
This study provides answers to questions about sustainability from the point of view of designing and making clothes, however, for further research, this type of garment design should be applied in the practice of industrial production. At the same time, the recycling of textile materials and modular and multifunctional approaches in the construction of clothing are topics that require more research, and in addition, it is necessary to carry out research on the economic aspect and the economic adaptation of sustainable fashion design.

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# NANOTECHNOLOGY IN THE TEXTILE INDUSTRY – A FUTURE THAT HAS ALREDY ARRIVED

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**ABSTRACT**

Nanotechnology is reshaping the textile industry by introducing innovative solutions that significantly enhance fabric properties and functionality. This field enables the development of textiles with advanced characteristics such as water and dirt resistance, antibacterial effects, and UV protection by incorporating nanoparticles like silver, titanium dioxide, and zinc oxide. Smart textiles, which respond to environmental changes, are emerging as a revolutionary trend, paving the way for new applications in medical, sports, and protective clothing. Despite its advantages, including increased product durability and reduced maintenance, nanotechnology presents challenges such as health risks, environmental concerns, and regulatory issues. The integration of nanomaterials raises questions about biodegradability and potential toxicity, requiring careful consideration. Nevertheless, prominent brands are already using nanotechnology to enhance their products, and ongoing research aims to address safety and sustainability. The future of textiles lies in the continued advancement of nanotechnology, enabling fabrics with self-healing properties, integrated health monitoring, and superior performance, which will further transform the industry.

**Key words**: nanotechnology, textile industry, antibacterial properties, UV protection, smart textile

## INTRODUCTION

Nanotechnology is the branch of science that identifies materials on a nanometer scale, and it also has ensured an enormous breakthrough in many industries, including the textile industry. Recently, textiles with functional properties created using nanotechnology have become less of a pipe dream and increasingly more accessible for real-world application. The rapid global expansion in the production of textile materials for medical, protective, hygienic, and sports applications over the past decade has rekindled interest in antimicrobial finishing for textiles. The textile industry faces challenges such as the need for improved abrasion resistance, water repellency, UV protection, as well as antibacterial and antistatic properties. These features can be improved by incorporating nanomaterials such as silver, zinc or titanium nanoparticles enhancing products' service life and functionalities. Nanotechnology furthermore helps to restore senile integrity in sports or medical textiles and in protective clothing, while also making it possible to produce smart fibres that react reversibly on environmental changes e.g. temperature variations and humidity swings [1-3]. The present paper focuses on nanotechnology in the textile industry and how it can help to change this field for better quality of product through meeting requirements of today's market allianc.

## UNDERSTANDING NANOTECHNOLOGY

Nanotechnology is a scientific field that involves the studies, design and application of materials in nanometer scale. At the nanoscale, many materials change behavior significantly due to a departure from the physical chemistry properties normally observed in this form that differ fairly dramatically at large dimensions. It spans multiple disciplines including chemistry, physics, biology and engineering leading to new solutions in electronics industry; medical devices applications of materials science such as Organ or Tissue on a chip; advanced energy systems developed from Materials Science for Energy Generation (n-type semiconductors and p-type) Material Culture. As well the textile field has experienced bio-material development by design using proteins, nucleic acids) Bioinspired Design.

Applications include the development of smart materials, improving product performance and advancement in disease diagnosis and treatment. By manipulating materials at the nanometer scale, nanotechnology holds the potential to revolutionize nearly every aspect of our daily lives, making products more efficient and functional. [2-5].


*Figure 14 Nanotechnology Applications [5].*

## OBTAINING NANOPARTICALS

The production of nanoparticles is the process by which materials are broken down to the nanometer scale, typically ranging from 1 to 100 nanometers. There are several methods for synthesizing nanoparticles, which can be classified into two main categories [6,7]:

**Top-down approaches:** These methods involve mechanically or chemically breaking down larger materials into smaller particles. Examples include:

- **Milling**: Mechanical grinding of materials into nanoparticles.
- **Etching**: Chemical reactions that remove layers of material from a surface.

**Bottom-up approaches**: These methods involve building nanoparticles from smaller units, such as atoms or molecules. Examples include:

- **Chemical synthesis**: Processes such as the sol-gel method, hydrothermal synthesis, or chemical reduction.
- **Biological methods**: Using microorganisms or plants to produce nanoparticles.

Each of these methods has its advantages and disadvantages, and the choice depends on the desired characteristics of the nanoparticles, such as size, shape, surface properties, and application.

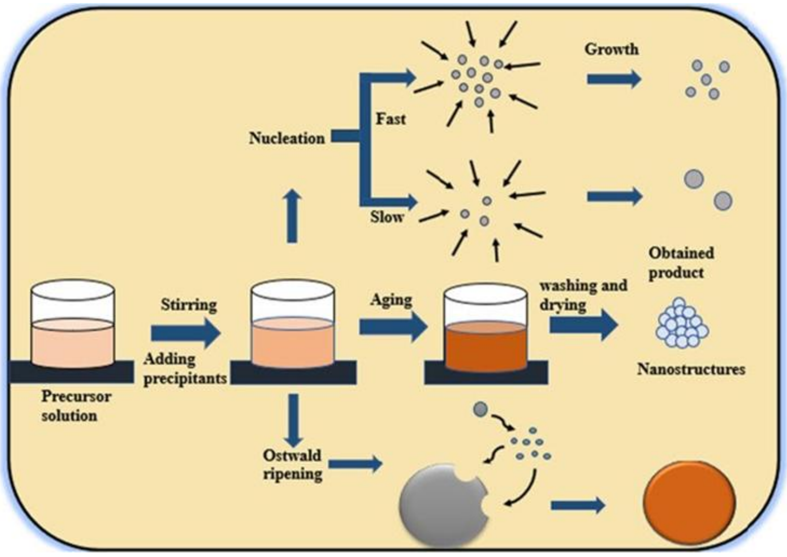


*Figure 15 Synthesis of Nanoparticles Using Bottom-Up Approaches (Chemical Methods) [7]*

**APPLICATION OF NANOTECHNOLOGY IN THE TEXTILE INDUSTRY**

Nanotechnology has already become an integral part of many industries, and the textile industry is no exception. The introduction of nanotechnology enables the creation of new functionalities in textile products that were previously unimaginable and opens the door to the development of new categories of textiles with improved properties. Some of the Major Examples for Nanotechnology in Textiles Industry

**Water and Dirt Resistance:**

One of the big things in nanotechnology for textiles has been creating superhydrophobic materials, inspired by the Lotus effect. These textiles apply nanotechnology to develop water and soil-repellent surfaces which in turn help the fabric stay cleaner for longer periods of time as well as aiding with reduced cold-water washing. Silicone-based nanoparticles are embedded in the textile fibers, forming a structure resembling micro and nano-pyramids. When water comes into contact with the fabric, it forms droplets that easily slide off the surface without being absorbed [4, 8, 10, 11].

**Applications:**

- Sportswear and related equipment
- Workwear
- Home textiles

*Figure 16 Lotus effect on textile material [11].*

**Antibacterial Properties:**

An obvious example of the advantages nanotechnology can offer for textiles is with regards to antibacterial effects. This is accomplished by incorporating silver, zinc or copper nanoparticles into the fabric. These nanoparticles destroy bacteria by reacting with them upon contact, preventing infections and unpleasant odors that naturally occur in sweat. Metallic nano particles (silver most notably) interact with bacterial cells, disrupting their enzymatic processes and ultimately destroying them. These are tiny, but powerful particles which require minute amounts [4, 10].

**Applications:**

- Medical clothing and linens
- Sports equipment
- Underwear and socks

**UV Radiation Protection:**

Functional textiles able to absorb and reflect UV rays, created by the use of nanoparticles Nanosized titanium dioxide ($TiO_2$) and zinc oxide (ZnO) particles that absorb UV light, or large molecules reflect it back have been used in the past to treat fabrics so as to provide a long-lasting protection against this harmful radiation to those using them. Titanium dioxide and zinc oxide are effective in blocking UV radiation, and nanoparticles of these materials are embedded directly into the textile fibers. Unlike standard UV protective coatings, nanotechnology allows for durable, long-lasting protection that does not wash out during laundering [4, 8].

**Applications:**

- Beachwear and outdoor clothing
- Sports apparel
- Protective work clothing

**Smart Textiles:**

Nanotechnology is a key component in the development of smart textiles. These are fabrics that can detect changes in the environment or the user's body and respond accordingly. For example, textiles can contain nanosensors that monitor changes in temperature, humidity, or even the user's heart rate.

Smart textiles use nanosensors and nanoelectronics to collect and transmit information. These fabrics can be connected to devices such as smartphones, enabling real-time monitoring of physiological data [4, 6].

**Applications:**

- Healthcare institutions
- Sports equipment
- Wearable devices

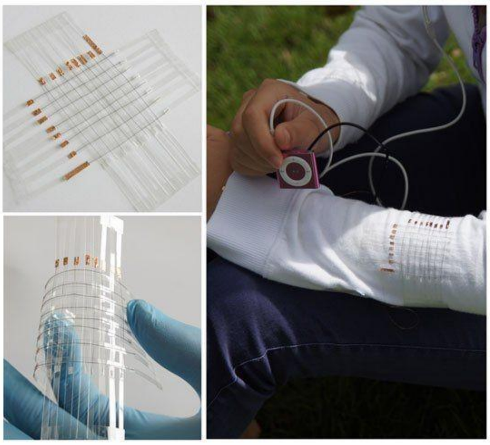

*Figure 17 Smart textile using nanotechnology [4].*

**Self-Healing Textiles:**

One of the revolutionary trends in the textile industry is the development of self-healing textiles. This innovation allows fabrics to "repair" themselves after damage, significantly extending product lifespan and reducing the need for replacement or repair. Nanocapsules containing polymers or chemical components are integrated into the fabric fibers. When damage occurs, the capsules open and release their contents, which then chemically bond and "heal" the wound in the fabric [4, 6].

**Applications:**

- Military and protective gear
- Industrial applications
- Fashion industry

**Increased Durability and Mechanical Properties:**

Nanoparticles and nanofibers can significantly enhance the mechanical properties of textiles, increasing resistance to tearing, abrasion, and wear. These materials provide strength and flexibility without adding weight to the fabric. Nanoparticles, such as graphene and carbon fibers, are integrated into textile fibers to create lightweight yet extremely strong materials. These fabrics are resistant to extreme conditions and tearing [4, 6].

Applications:

- Military and protective clothing
- Industrial apparel
- Sports equipment

## ADVANTAGES AND DISADVANTAGES OF THE APPLICATION OF NANOTECHNOLOGY IN THE TEXTILE INDUSTRY

Nanotechnology brings numerous advantages to the textile industry, including enhanced material functionality, increased durability, improved user protection, and economic benefits. Nanoparticle-infused fabrics last longer, meaning they do not need to be replaced as often or regularly maintained and thus lower production costs and tenants. On top of this, their dirt-repellent and antibacterial qualities help to prevent excessive water and chemical consumption that saves costs in the long run whilst also minimising environmental impact. Nanotechnology also contributes to the reduction of resources consumption and emission, avoiding as much as possible harmful chemicals. Greater resistance to wear, water, and UV radiation extends the product lifecycle. It also boasts antibacterial properties hence makes it hygiene and completely prevents bad odor especially for sportsman ware, medical attire.

However, nanotechnology also brings numerous disadvantages. First, there are concerns about the potential toxicity of nanoparticles, such as silver and titanium dioxide, which can penetrate the skin or be inhaled, leading to adverse effects. The long-term effects on human health are still not fully understood. In addition, many nanomaterials are not biodegradable, which can cause them to accumulate in nature and potentially harm ecosystems; their presence in water systems is of particular concern, as nanoparticles can contaminate water sources. Also, the legal framework for the regulation of nanotechnology is still under development, which requires stricter regulations to ensure the safety of the use of nanoparticles in textiles and provide the necessary transparency to consumers. Finally, the production of textiles using nanotechnology implies high research and development costs, resulting in higher product prices, which may limit the availability of these innovative products in the market, especially in countries with lower purchasing power [4-10].

## CONCLUSION

Nanotechnology has already revolutionized the textile industry by introducing innovations that enhance functionality, durability, and sustainability of materials. Smart, antibacterial and waterproof fabrics are examples of innovation that not only make for better user experience but also minimize the footprint on nature. Currently the health and safety of nanotechnology are still in question, regulatory systems including those at an international level have not figured out a solid way to deal with them but regardless these challenges it has proven that this will impact significantly on the future technology in textiles, which already is benefitting from features like stain protection. Nanotechnology also will be important in mainstreaming the development of advanced "smart" fabrics that can adapt to changing environmental conditions and wearer preferences. There will be even more exciting enhanced capabilities in functional textiles including self-monitoring health sensors, miraculous self-reporous materials and fabrics that enhance protection from the most extreme conditions. At the same time, research is expected to investigate safer nanoparticles and environmentally friendly materials for sustainable manufacturing. When nano fabrics become more ubiquitous due to the technologies behind them being widely shared and thus accessible on a wider scale, they can almost replace any type of fabric industry from textile fashion all through medicine.

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# ABSTRACTS

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*14th International Scientific-professional conference*
*25th October, 2024, Zrenjanin, Serbia*
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# DIGITAL DECONSTRUCTION PROJECT – EXPLORING THE POSSIBILITIES OF RE-DESIGNING DIGITAL DESIGNS FOR MORE SUSTAINABILITY

**Annette Kölling**
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**ABSTRACT**

Digital Deconstruction is a design concept that explores the possibility of creating new, appealing designs from an existing pattern, e.g. a classic women’s shirt, while minimizing waste using the Computer-aided Design system Clo3D. The focus is on determining how many of the existing pattern pieces can be re-used with as little waste as possible. This paper presents the preliminary work for the main research topic, “Fashionable Recycling of Overproduction through AI-Automated Design Suggestions”. The starting point of this project was a pattern block from the Modular Library of Clo3D, which is generally accessible within the software. The results indicate that while it is indeed possible to re-design a CAD file of an existing garment, the new designs generated more waste than acceptable, with an average wastage rate of over 75%. However, 25% of the new designs successfully used 100% of the existing pattern pieces without creating any waste. For future iterations of this study, it is recommended to start with a zero-waste pattern system to reduce waste and create more commercially viable designs within the project. Next steps will involve investigating the best methods to connect multiple designs with a single pattern and automating tasks in Clo3D through scripting.

**Key words**: Clo3D, CAD, design automatization, overproduction, re-design garments, fashion design, automatization, recycling, reduce waste

# FREQUENCY SELECTIVE SURFACE (FSS) BASED ON TEXTILE : A METAMATERIAL OPTIMISATION DESIGN

**Amine Haj Taieb*, Hanen Zribi**
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**ABSTRACT**

We are surrounded by weaves, some of them transport sound to our ears, stimulate the retinas of our eyes, bring radio, television and endless streaming content to our devices.
All these different waves are governed by the same fundamental physical principles. And recently there has been a revolution in our ability to control these waves using materials, known as metamaterials.
In this work, a review of the potential applications of metamaterial is presented such as sound silencers, sonar deflectors, earthquake dampeners, heat shields, invisibility cloaks.
Second, the design of a Frequency Selective Surface (FSS) based on textile for selecting frequence is analyzed. This FSS or "spatial filter" can be integrated into the materials to obtain a metamaterial.

**Key words**: Metamaterial, barriers effects, Frequency Selective Surface, optical illusion, invisibility

# APPLYING TRADITIONAL CLOTHING CONSTRUCTION METHODS TO ACHIEVE ZERO-WASTE IN CONTEMPORARY FASHION DESIGN

**Belma Kapić**
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## ABSTRACT

Clothing can become waste for several reasons, including physical damage, disposable design, or changing fashion trends. In addition to clothing as the final product, the fashion industry also generates a significant amount of waste during its production process, mainly due to the inefficient use of resources. In this sense, the fashion industry makes a significant contribution to environmental pollution, which has encouraged the development of sustainable practices, including the "zero-waste" approach. The zero-waste approach helps evaluate resource use by focusing on maximizing fabric utilization, reusing components, and extending the lifespan of clothing. This paper integrates traditional clothing construction methods, known for their efficient use of fabric, modular designs, and multifunctional garments, with contemporary design practices following a zero-waste approach. In making the traditional Bosnian-Herzegovinian costume, minimal cutting and clever fabric shaping, joining, and decorating helped reduce waste. By combining these heritage techniques with innovative tailoring and digital tool CLO 3D, specialized for the fashion industry, this work shows how traditional craftsmanship can serve as a foundation for creating sustainable fashion collections in the 21st century. Through case studies and practical applications, this research provides a framework for fashion designers to integrate a zero-waste approach rooted in cultural heritage, contributing to the wider sustainability movement in fashion design.

**Key words**: fashion waste, sustainable fashion, zero waste, Bosnian-Herzegovinian costume, CLO 3D

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