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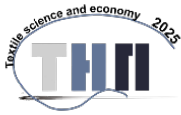
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# **TEXTILE SCIENCE & ECONOMY XV**

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## FOREWORD

The Technical Faculty “Mihajlo Pupin” of the University of Novi Sad is organizing the Fifteenth International Conference “XV Textile Science and Economy” (TNP2025).

Guided by the belief that only good people create good products, our conference brings together experts from both academia and industry. Year after year, we follow the development of science and industry in this sector. From the very beginning, we have collaborated with scientists from all over the world, from America to China. Many business professionals from the manufacturing sector have also participated in our conferences. Experts from the French company Lectra have undoubtedly made a significant contribution to improving quality. They have provided us with insights into modern economic trends as well as global trends in textiles and materials. Not only have they enabled access to information about developments in this field, but they have also equipped us with valuable equipment. In addition, for several years now we have owned a CAM machine from the Industry 4.0 generation. Most of the equipment was acquired through an IPA project within our cooperation with the Faculty of Arts and Design of the West University of Timișoara.

Meetings of experts from academia and industry at our conferences have continuously raised the level of our international cooperation. This has enabled the exchange of our professors and students within the Central European CEEPUS program, in which around 50 of our students have participated. Seventeen of our students and 11 of our professors have taken part in the Erasmus program. Around 40 textile students completed internships at the German company “Pirinteks,” while about 15 students and two professors participated in two programs at Donghua University in Shanghai. Under the project titled “Innovative Approach in the Education of Textile Engineers for the Serbian Textile Industry,” we succeeded in including the University of Novi Sad in the World Alliance of Textile Universities “Belt and Road,” alongside 45 prestigious universities worldwide, at a conference held at Donghua University in Shanghai in 2018. It is also a great achievement that we have been selected as a member of the governing board of this alliance.

Our vision is to educate students who, with their knowledge, will easily secure positions required by both domestic and international companies. Our goal is for our students to become a driving force in companies within the Serbian textile industry.

We aim to further elevate the level of the Conference so that it becomes a meeting place for both domestic and international scientists and business professionals who establish new partnerships, while also involving our students.

Finally, I would like to thank all past participants of our conferences and everyone who has contributed to the success we have achieved.

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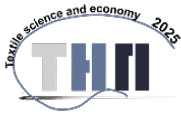


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*Textile Science and Economy*  
15<sup>th</sup> International Scientific-professional conference  
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Technical faculty „Mihajlo Pupin“, University of Novi Sad



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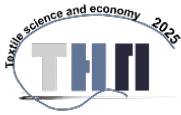
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## **DEFORMATION PROPERTIES OF WOVEN TEXTILE MATERIALS**

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### **Abstract**

*The deformation properties of woven textile materials depend on the physical and mechanical properties of the yarn, the fabric weave, and the warp and weft densities. This study analyzes fabric parameters at the yield and breaking points. Plain weave, 3/1 twill, and 4/1 twill fabrics were examined, differing in weft density and yarn type. All fabrics were produced using the same warp under industrial weaving conditions. Based on the experimental results, relationships were established that enable prediction of the yielding behavior of plain weave, 3/1 twill, and 4/1 twill fabrics subjected to tensile loading in the weft direction.*

### **INTRODUCTION**

Under the action of external forces, changes in the shape of fabrics occur. The deformation of the material depends on the type, direction, and intensity of the applied force, as well as on the duration of loading and the relaxation time. Shape changes in fabrics arise from disturbances in their internal structure [1, 2]. More pronounced structural changes in woven materials occur when the applied tensile force exceeds the force corresponding to the yield limit [3].

Woven fabrics are highly anisotropic, which complicates the prediction of their mechanical behavior [4, 5]. Various methods and experimental devices have been developed to characterize the mechanical properties of fabrics [6–8], with the aim of explaining shape changes occurring during use. In addition, predictive approaches for fabric breaking forces and dimensional changes up to rupture have been reported [9, 10]. The effect of anisotropy in plain weave fabrics on elastic constants in different loading directions has also been investigated [11].

Despite these advances, the available literature provides limited information on methods for determining limit loads that lead to significant fabric deformation prior to rupture. Therefore, this paper proposes a method for determining limit load values based on analysis of the force–elongation curve. The method defines the load limit up to which the material exhibits substantial resistance to tensile loading, corresponding to the onset of material yielding.

### **MATERIALS AND METHODS**

The mechanical properties of 60 different woven fabrics were analyzed, including 20 plain weave fabrics, 20 3/1 twill fabrics, and 20 4/1 twill fabrics. All fabrics were produced under industrial conditions on an electronically controlled weaving loom, using yarns composed of a 50:50 polyester/cotton (PES/CO) fiber blend.

All 60 fabrics were woven with the same warp yarn of linear density  $25 \times 2$  tex (breaking force: 1157 cN; elongation at break: 8.5%; twist:  $600 \text{ m}^{-1}$ ) and a warp density of  $27 \text{ cm}^{-1}$ . The weft yarns used had linear densities of  $25 \times 2$  tex (breaking force: 1157 cN; elongation at break: 8.5%; twist:  $600 \text{ m}^{-1}$ ), 50 tex (breaking force: 1033 cN; elongation at break: 9.3%; twist:  $520 \text{ m}^{-1}$ ), 41.67 tex (breaking force: 807 cN; elongation at break: 8.8%; twist:  $551 \text{ m}^{-1}$ ), and 29.41 tex (breaking force: 609 cN; elongation at break: 6.9%; twist:  $630 \text{ m}^{-1}$ ). For each

weft yarn type, fabric samples were produced with weft densities of 14, 16, 18, 20, and 22  $\text{cm}^{-1}$ .

The tensile properties of the fabrics were measured using a MesdanLab Strength Tester dynamometer, in accordance with ISO 13934-1 [12]. The extension rate of the fabric specimens until rupture was 100 mm/min. In addition, force–elongation data were recorded for all analyzed fabrics in the weft direction. The obtained force–elongation curves were approximated using ninth-degree polynomial functions.

The yield limit for all 60 fabrics in the weft direction was determined from force–elongation curves using the procedure described in [13].

## RESULTS AND DISCUSSION

When a fabric is subjected to a load, its structure changes, with the extent of these changes depending on the intensity, direction, and duration of the force, as well as on the fabric’s construction.

In order to objectively examine the influence of weft density on the force at the yield point of the analyzed fabric samples, all other constructional and structural parameters must be identical (fiber composition, linear density of warp and weft yarns, weave, and warp density). Therefore, all analyzed fabrics were produced using the same warp.

Based on the obtained results, histograms were plotted to illustrate the effect of weft yarn density on the values of breaking force and breaking elongation, as well as on the force and elongation at the yield point of the fabric in the weft direction. The corresponding colors denote the type of weft yarn, which allows the influence of the weft yarn type on the force and elongation values at the yield point of the analyzed fabrics to be observed.

The influence of weft yarn density on the deformation properties (yield and break behavior) of the analyzed fabrics in the weft direction is presented in Figures 1, 2, and 3.

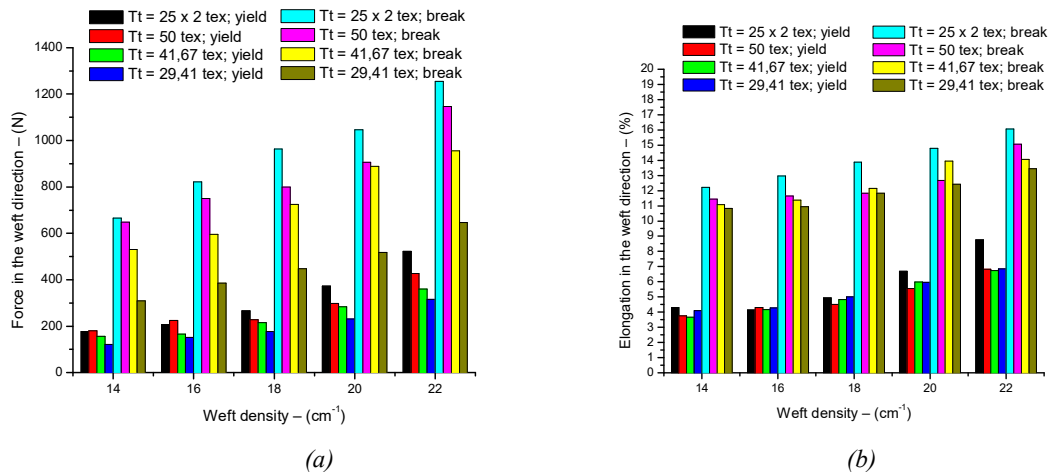


Figure 1. Effect of weft density on tensile force (a) and elongation (b) of plain weave fabrics

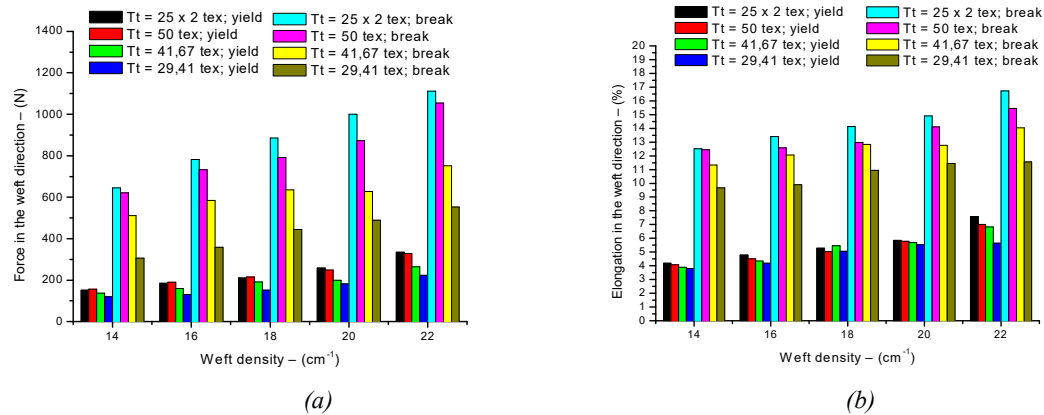


Figure 2. Effect of weft density on tensile force (a) and elongation (b) of fabric in 3/1 twill

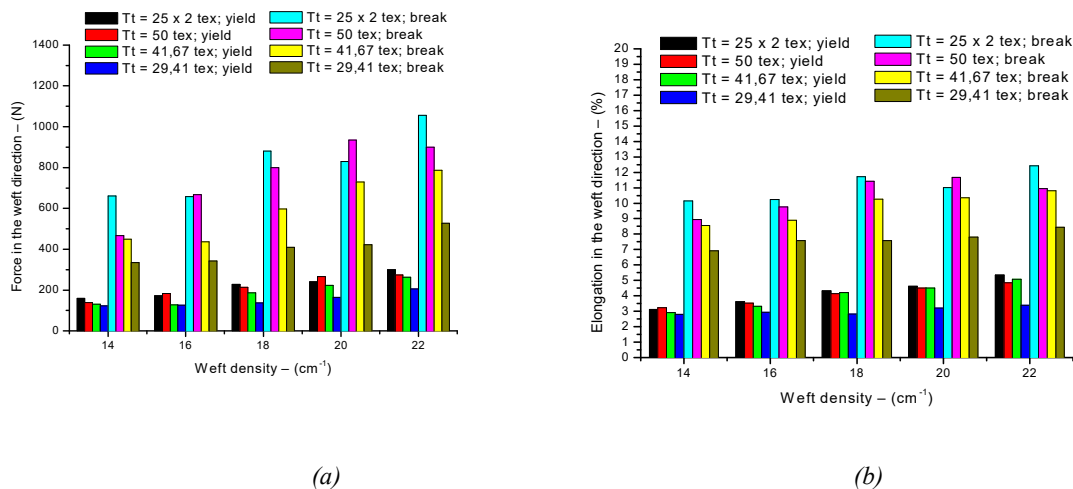


Figure 3. Effect of weft density on tensile force (a) and elongation (b) of fabric in 4/1 twill

The results show an increasing trend in the breaking characteristics and the yield-point properties with increasing weft yarn density.

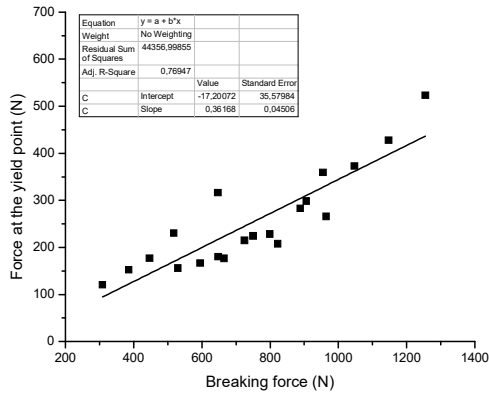
The mechanical properties of the weft yarns have the expected influence on the fabric's breaking properties and on the values of the parameters at the yield point in the weft direction. Specifically, the lowest breaking forces and forces at the yield point were observed in fabrics produced with weft yarns of 29.41 tex linear density.

Furthermore, the results indicate that the yield-point forces of fabrics in the weft direction are generally higher for fabrics with a plain weave compared to fabrics with twill weaves. This is an expected outcome, since the number of interlacing points relative to the weave repeat is higher in plain weave fabrics than in the analyzed twill fabrics [14], resulting in a larger contact area between warp and weft yarns, which contributes to higher fabric strength. Fabrics with a 4/1 twill weave exhibited the lowest breaking and yield-point forces, assuming identical warp and weft yarns and densities.

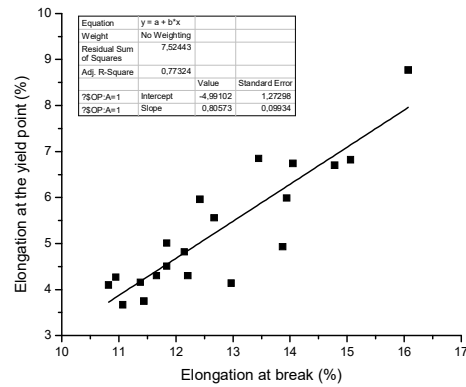
An increase in the weft yarn density in the fabric contributes to a rise in the proportion of the yield-point force within the breaking force in the weft direction. For plain weave fabrics, this proportion increases in the range of 25.2–51.8%, for 3/1 twill fabrics in the range of 23.5–40.4%, and for 4/1 twill fabrics in the range of 24.25–39.11%.

Figures 4, 5, and 6 present graphs illustrating the relationship between breaking elongation and yield-point elongation in the weft direction for all analyzed fabrics.

The relationship between the yield-point parameters (the maximum of the first derivative of the force–elongation curve) and the breaking characteristics (measured using a dynamometer) is expressed by a linear equation of the form:  $y = a + bx$ .

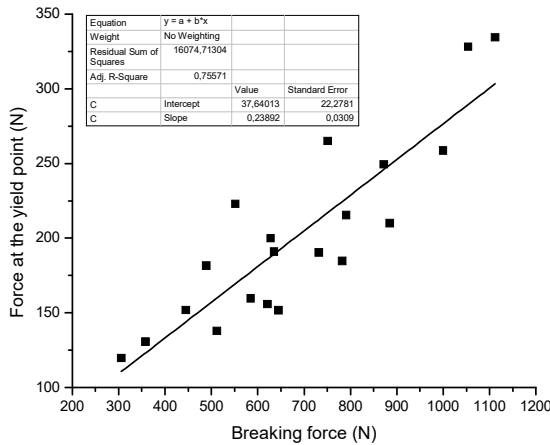


(a)

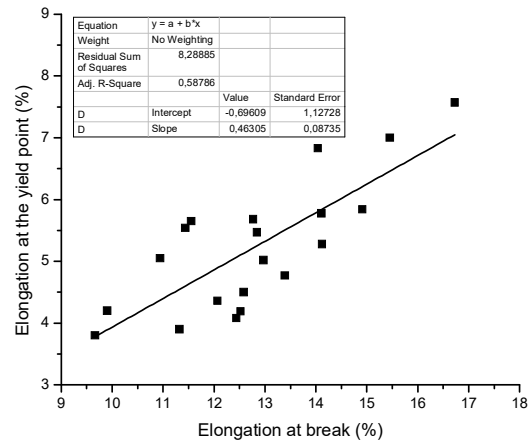


(b)

Figure 4. Relationship between force (a) and elongation (b) at the yield point and at break in the weft direction of fabrics with a plain weave



(a)



(b)

Figure 5. Relationship between force (a) and elongation (b) at the yield point and at break in the weft direction of fabrics with a 3/1 twill weave.

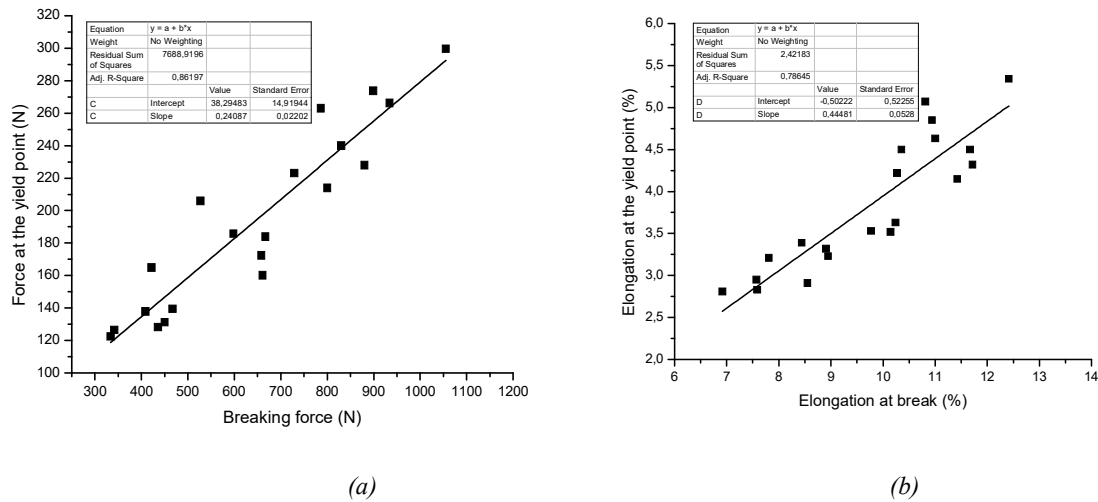


Figure 6. Relationship between force (a) and elongation (b) at the yield point and at break in the weft direction of fabrics with a 4/1 twill weave

Using the obtained data, the limit values of force and elongation for the corresponding woven fabrics with plain weave, 3/1 twill, and 4/1 twill constructions made from a 50:50 polyester/cotton (PES/CO) fiber blend were determined.

## CONCLUSION

The breaking force and elongation of a fabric are key parameters characterizing its mechanical properties. However, these data alone are insufficient to fully understand the mechanical behavior of woven fabrics. Textile materials are exposed to various loads during use. Knowledge of limit loads, which a material can sustain without compromising its properties, is essential for preserving fabric structure.

Fabric deformation depends on structure, construction, and the intensity and direction of applied loads. Defining parameters at the yield point and correlating them with breaking characteristics provides a basis for predicting fabric behavior during use. These findings can further guide the optimization of woven fabric structure and construction for specific applications.

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# **THE ROLE AND IMPORTANCE OF THE WORLD TEXTILE UNIVERSITY ALLIANCE FOR THE ADVANCEMENT OF THE GLOBAL TEXTILE INDUSTRY**

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## **ABSTRACT**

*The World Textile University Alliance (WTUA), founded in 2018 at Donghua University under the Belt and Road Initiative, connects 33 textile universities from 19 countries to advance education, innovation, and sustainability in the global textile sector. Through joint training, international laboratories, scholarships, conferences, and initiatives such as the 2025 China-Africa Textile Forum, Green Capacity Cooperation Forum, and SUSFUTURE exhibitions, WTUA promotes knowledge transfer, green technology adoption, and resilient supply chains. Applying innovation network theory and the Triple Helix model, this study evaluates WTUA's mechanisms, achievements, and future prospects. It highlights contributions to BRI-aligned growth while addressing challenges like geopolitical risks and funding constraints, offering insights for stronger academic-industry networks.*

Keywords: WTUA, textile education, university-industry collaboration

## **1. INTRODUCTION**

The textile and clothing business around the world is large, worth around 1.7 trillion US dollars, and provides work for many people from raw materials to finished goods. But now in 2025 and into 2026, it faces many difficulties. Economic conditions change quickly, consumers want different things, and new technology changes old ways fast. One big problem is the need to become greener because the field adds 2 to 8 percent of global greenhouse gases, uses much water, and creates waste. Growth is expected to be small, just a few percent in 2026, due to high costs, careful buying by people, and stronger rules for using materials again in a circle. Making clothes still depends much on oil-based materials, but more people want plant-based or recycled options to meet green rules and buyer wishes [1][2].

Groups formed by universities offer useful ways to deal with these issues by sharing knowledge, doing joint research, letting people move for study, and working with companies. These connections speed up new ideas, make it easier for graduates to find jobs, and support green methods. The World Textile University Alliance (WTUA) is one clear example. It was set up by Donghua University and started officially on December 8, 2018, during the World Textile and Apparel Education Conference in Shanghai. The alliance brings together universities with special knowledge in textiles to build better teaching and business ties, especially in countries along the Belt and Road. China holds the biggest part of the world textile output, more than half, and sends out about 37.5 percent of clothes, giving a solid base with strong production and teaching at places like Donghua and others [3][4].

This paper examines the role and value of WTUA. It reviews what others have written about university groups and problems in textiles, describes the structure and work of the alliance, looks at what it has done based on real events and reports, and discusses what this means for progress in the field. The textile business must change to be greener, use numbers more, and follow rules, and WTUA helps by getting schools to work together. For example, in 2026 trade problems and economic slowdown make getting materials hard, but groups like this share solutions. China has invested more than 6.7 billion

dollars overseas in textiles from 2015 to 2020, and WTUA supports this through teaching and new ideas [5].

The field also has long-standing issues like changing prices for materials, green rules, lack of trained workers (20 to 30 percent short in skilled jobs), and supply chains that break easily from world events. In 2026, US-China trade issues, new making places like Vietnam and Bangladesh, green taxes, regional trade agreements, digital making, strict green rules, and closer production all change how business runs [6]. Universities must teach new skills for this, such as green design, smart production, and circular business models. WTUA does this by linking schools from different areas, improving teaching, and helping companies.

At the beginning, WTUA had 385 people from 127 schools and groups in 26 countries at the first meeting. Now it has more connections, like with UNIDO and CNTAC in 2025 events. This helps share green technology and connect school teaching with business needs. The paper uses real examples like the 2025 China-Africa Textile and Apparel Forum and the Green Capacity Cooperation Forum to show WTUA is active [7]. In the end, WTUA not only improves teaching but makes the business stronger against difficult times. WTUA organizes talks and shows to help. For instance, in 2026 the SUSFUTURE design week with WTUA includes a green fashion event in Serbia from April 20 to 23, with schools like University of Novi Sad joining [8]. This shows WTUA expands to more places and topics.

China's position is important, with huge production but now higher labor costs and green rules, so it needs new technology and world links. WTUA helps by bringing schools together for joint projects, like labs for new fibers. The paper aims to show how such groups matter for the business to grow.

## **2. LITERATURE REVIEW**

Many studies look at how universities and companies work together in textiles and fashion to push new ideas and fix problems in the field. These studies often point out that such partnerships bring benefits like better job chances for students, access to special tools and knowledge, and quicker move to green ways of working. For example, research on wool-centered projects shows how collaboration from yarn development to sustainable products helps students, companies, and teachers in practical ways. Another study compares China and Hungary in fashion teaching and finds that university-industry cooperation improves teaching quality, helps teachers learn new methods, and supports overall school and teacher development [9].

In the wider textile area, writings discuss how partnerships and alliances help the move to sustainability by building networks among organizations for better rules, circular methods, and fair teaching. Research on international partnerships in textiles looks at different forms of cooperation, like strategic alliances and joint ventures, and their role in sharing knowledge and planning changes, especially in areas with limited resources [10]. Some papers review many partnerships in the textile field and show how they are set up to focus on sustainability goals.

Fashion design education gets attention in studies that stress the need to include sustainability fully in teaching. One important paper argues that fashion schools should balance craftsmanship, artistic skills, and business knowledge while making sustainability a key part. It reviews how sustainable fashion appears in education in different places, including Western Europe, East Asia, and non-European countries, and notes that in some contexts like Poland, it has grown but still faces challenges in making it deep in curricula rather than just added activities [17]. Another study explores how to implement education for sustainable development as a main guide in fashion and apparel design teaching in places like Germany and Iran, using design-based research to find practical ways.

Broader writings on global textile education networks and sustainability cover how schools can promote green practices through open resources, new curricula, and international projects. For instance, EU projects like Fashion DIET create teaching modules on sustainable fashion design, production technologies, and market orientation to update skills for teachers and students in the textile sector. Other research looks at how fashion programs in the US and elsewhere add zero-waste projects or sustainability courses to prepare graduates for industry needs. Studies also discuss how alliances and partnerships, like those under UN initiatives or regional clusters in Europe, support innovation, resource efficiency, and high-value markets in textiles.

In the context of Belt and Road and global value chains, some papers examine how China’s role in textiles leads to more education and skills training links with other countries. Writings on supply chain changes and trade in 2026 highlight uncertainties from tariffs, green regulations, and digital shifts, showing why education networks matter for building resilient chains and skilled workers [19-20].

### 3. WTUA MEMBERSHIP



Figure 1: Mapping of WTUA member countries

#### International members:

- ❖ Aalto University (Finland)
- ❖ Amirkabir University of Technology (Iran)
- ❖ Bahir Dar University (Ethiopia)
- ❖ BGMEA University of Fashion & Technology (Bangladesh)
- ❖ Cambodian Garment Training Institute (Cambodia)
- ❖ ENSAIT–Ecole Nationale Supérieure des Arts et Industries Textiles (France)
- ❖ Kulob Institute of Technology and Innovation Management (Tajikistan)
- ❖ Moi University (Kenya)
- ❖ Mongolian University of Science and Technology (Mongolia)
- ❖ National Textile University (Pakistan)

- ❖ Reutlingen University of Applied Sciences (Germany)
- ❖ Sudan University of Science and Technology (Sudan)
- ❖ Suez Cannel University (Egypt)
- ❖ Tashkent Institute of Textile and Light Industry (Uzbekistan)
- ❖ The Royal University of Fine Arts (Cambodia)
- ❖ Universidad Politecnica de Madrid (Spain)
- ❖ University of Edinburgh (UK)
- ❖ University of Gezira (Sudan)
- ❖ University of Novi Sad (Serbia)
- ❖ University of the South Pacific (Fiji)
- ❖ University of Westminster (UK)
- ❖ Uzbek Research Institute of Natural Fibers (Uzbekistan)

#### **In China**

- ❖ Beijing Institute of Fashion Technology
- ❖ Dalian Polytechnic University
- ❖ Donghua University
- ❖ Hebei University of Science and Technology
- ❖ Jiangnan University
- ❖ Qingdao University
- ❖ Soochow University
- ❖ Tianjin Polytechnic University
- ❖ Tibet University
- ❖ Wuhan Textile University
- ❖ Xi'an Polytechnic University
- ❖ Xinjiang University
- ❖ Zhejiang Sci-Tech University
- ❖ Zhongyuan University of Technology

### **3. PURPOSE OF ESTABLISHING THE WORLD ASSOCIATION OF TEXTILE UNIVERSITIES**

The purpose of the WTUA is as follows, with a specific focus on the textile and related industry:

- Capitalise on the unprecedented opportunities afforded by the BRI
- Promote common development and prosperity
- Strengthen academic and scientific cooperation
- Promote scientific and technological progress
- Promote art design in textile, apparel and related industries

Activities relating to talent development include:

- Promote joint talent training
- Hold seminars and facilitate exchanges
- Collaborate to meet the talent needs of textile enterprises
- Conduct government-industry-university research

- Seek governmental support to expand the number of scholarships for students studying in Alliance member universities, for long- and short-term study periods
- Establish a Belt and Road scholarship for outstanding international students jointly with related enterprises
- Formulate a method for mutual recognition of credits
- Explore joint training of high-level talents
- Organise the Alliance members to set up an editorial committee for publishing professional teaching materials of courses taught in English and research-based working papers.

With regards to science and technology:

- Collaborate in scientific and technological innovation.
- Establish a cluster of Belt and Road scientific and technological consulting service stations and international laboratories
- Facilitate the exchange of knowledge and new technologies among experts and industries from Belt and Road countries and beyond
- Hold annual conferences on technical developments and exchanges.

In relation to culture and arts promotion:

- Strengthen fashion, cultural and people-to-people exchanges
- Host Belt and Road International Fashion Weeks and invite each member to participate
- Conduct academic exchanges and research projects pertaining to themes such as the Belt and Road fashion trends, fashion and folk customs and language and culture
- Explore the Belt and Road historical and cultural heritage
- Hold a Belt and Road World Youth Fashion Design Competition
- Demonstrate the spirit of friendly cooperation of the Belt and Road countries by organizing the exchange of young artists and designers from all over the world and encouraging young designers worldwide to form a joint fashion design studio.

The WTUA will particularly consider all of the above at its planned General Assembly. The Assembly, and all other events, will be undertaken on a non-profit, break-even, basis to allow opportunities for all Alliance members to host events and members will have discretion to levy fees to enable costs to be recovered.

To encourage and promote membership, the WTUA is inclusive and interested parties can submit an application to the Secretariat (see below) for consideration by the Steering Board. The Steering Board will decide, taking into account views of Alliance members as appropriate. In the event a member wishes to withdraw from the Alliance, a notification in writing should be received by the Secretariat three months in advance of the intended withdrawal date and the Secretariat will amend the Alliance's official website on the date of withdrawal.

There is also the possibility that Special Interest Groups, with devolved responsibilities, may be established at the discretion of the Steering Board.

#### **4. ACCOMPLISHMENTS AND OUTPUTS WTUA**

WTUA is working on a large number of activities to position itself as a world leader in the cooperation of textile universities. Some of these activities are:

#### **4.1. Annual advanced training program for international cooperation in the textile and clothing industry's production capacity.**

Event Date: Annually since March 2019

Program: Advanced Seminar for Textile Industry International Cooperation

Participants: 30-40 individuals from WTUA members

Countries Represented: Pakistan, Uzbekistan, Afghanistan, Iran, Serbia, Ethiopia, Cambodia, etc.

Participant Profiles: Textile industry executives, research institute experts, university professors

Agenda: Three-week seminar and discussions

#### **4.2. The Chinese Traditional Costume Program (3S-CTCP) hosted by Donghua University (DHU) is a sub-program of Shanghai Summer School.**

It aims to help the participants gain a profound understanding of Chinese traditional costumes as well as their modern development.

Inaugural Textile Talent Training:

- Four Modules: Technology Lectures, Workshops, Cultural Visits, Industry Tours
- Participants from Textile/Design-focused Universities
- 



Picture 2: Participants of the program, including a student from Serbia

#### **4.3. Scholarships for International Students**

DHU's 'Belt and Road' scholarships expand educational horizons.



Figure 3: Students - beneficiaries of scholarships

#### Scholarship Initiatives

- Increasing Numbers of Scholarships
- Benefiting Teachers, Professionals, and Students

#### Silk Road and Shanghai Government Scholarships

- Existing Scholarship Programs
- Complementing "Belt and Road" Scholarships
- Supporting International Students

#### DHU's Commitment

- Establishment of Scholarships
- Expanding Educational Opportunities

#### Strengthening Textile and Design Education

#### 4.4. Collaborative Research and International Project Applications with Member Institutions

- China-Central and Eastern European Countries Joint Education Program, joint application with University of Novi Sad, 2019
- Innovative Talent Cultivation Program in New Textile Finishing Technologies, joint application with the University of Twente, and the University of Louisville, 2019
- International Joint Laboratory for Advanced Fiber and Low-Dimension Materials, joint application with Bar-Ilan University, Stony Brook University, and Leibniz Institute for Polymer Research, 2019
- International Joint Laboratory for Textile Intelligent Manufacturing and Engineering, joint application with Jeonbuk National University, the Polish Academy of Sciences, and Khalifa University, 2021

#### 4.5. Publications

Textbooks and research papers related to textile and fashion technology, fashion industry, and fashion design in 'Belt and Road' countries have been published.

- Textbooks
- Dissertations
- Journal papers
- Conference proceedings

#### 4.6. Conference & Seminar

Facilitating Exchange in Textile and Fashion-Related Fields between Member Institutions and Industry

- Advanced Seminar on Promotion of Development Capability in Textile & Garment Industry for Lancang-Mekong Countries, 2019
- 6th International Conference on Electrospinning, Shanghai, 2019
- International Sustainable Fashion Symposium Between China and Central and Eastern European Countries, 2020
- How Sustainable Fashion is Reshaping Lifestyles? Intertextile, Shanghai, 2021
- Sustainable, Green, and Inclusive Development Seminar for the Fashion Industry, Shanghai, 2021
- Dual Circulation Strategy and 'Belt and Road' Sustainable Development Forum, Shanghai, 2021
- International Conference on Advanced Textile Science and Technology & World Textile University Alliance Annual Meeting, 2022, 2023, 2024
- Seminar on Responsibility, Innovation, and Collaboration: New Opportunities for Driving Sustainability in the Home Textile Industry, 2025
- Seminar on Synergizing Technology, Design, and Business for Sustainable Technical Textiles, 2025
- Global Forum on Green Capacity Cooperation and Industry–Education Integration in Textiles & World Textile University Alliance Annual Meeting, 2025

#### 4.7. Exhibitions & Shows

Fostering students and personnel from WTUA member institutions to participate in international exhibitions and present their work.

- Shanghai “Belt and Road” International Fashion Week, 2019
- Splendor of Embroidery Art - Promotion Conference of Guizhou Intangible Cultural Heritage in Brazil, 2019
- From Shanghai with Love, Edinburgh Fringe, 2016-2019
- Fiji Fashion Week, 2019
- Colorful Fashion Exhibition under the Belt and Road Initiative, 2019
- Fashion Trend Photo Exhibition of Countries Along the 'Belt and Road' Initiative, 2019
- The 25th International Young Designers Contest Admiralty Needle, 2019
- The 28th Fashion Mill Festival in Minsk, 2019
- CHINA DAY, Tashkent Fashion Week, 2018
- SUSFUTURE International Sustainable Design Exhibition, 2024, 2025



Picture 4: Participants of fashion shows

## 5. FUTURE PLANS

### 5.1 Educational Enhancements

#### a. Cooperative Curriculum

- Joint Textile & Fashion-related Modules: Develop specialized courses.
- Online courses: Promote virtual learning.
- Faculty Exchange: Share expertise & teaching methodologies across borders.
- Dual Degree Programs: Explore joint degrees with partner institutions to offer students an international experience.
- Accreditation: Pursue international accreditation to enhance program recognition.

#### b. Workshops & Seminars

- Knowledge Exchange: Facilitate workshop and seminars.
- Best Practices: Collaborative Workshops on Member Strategies.
- Virtual Engagement: Webinars to connect members globally.
- Student Collaboration: Encourage cross-institutional student projects and knowledge sharing.
- Continuing Education: Offer ongoing professional development opportunities for member faculty.

### 5.2 Innovation & Research

#### a. Design Initiatives

- Global Competitions: Highlighting sustainable designs with collaborative judging & mentorship
- Global Showcases: Elevate winners on international platforms.
- Student Innovation Labs: Establish innovation labs where students can work on diverse projects.
- Intellectual Property Management: Develop a framework for handling intellectual property arising from collaborative projects.

#### **b. Research Collaborations**

- Grant Partnerships: Collaborate to secure funding.
- Joint Publications: Broaden the impact of research.
- Cross-Disciplinary Research: Encourage interdisciplinary research teams to work together.
- Research Centers: Establish dedicated research centers.

### **5.3 Alliance Strengthening**

#### **a. Membership & Outreach**

- Targeted Campaigns: Identify & recruit potential institutions.
- Membership Benefits: Showcase the value of joining WTUA.
- Feedback Loop: Regular surveys to understand member needs.
- Alumni Engagement: Foster new members.
- Strategic Partnerships: Collaborate with industry associations to attract new members.

#### **b. Networking & Integration**

- Digital Collaboration Platform: Foster constant communication.
- International organizations: Develop relationship with international & regional organizations.  
Exchange Programs: Enhance global exposure for students & faculty.
- Industry Partnerships: Collaborate with textile industry leaders for research and education.
- Marketing & Branding: Develop a cohesive branding strategy to promote the alliance.
- Special Interest Group: Form specialized groups to focus on specific topics or areas of interest within our alliance.

## **6. CONCLUSION**

The World Textile University Alliance provides a practical and effective example of how universities from different countries can cooperate to support the progress of the global textile industry. Through its emphasis on talent training, collaborative research, cultural exchange, and the development of a shared international think-tank focused on textiles, fashion, and related technologies, WTUA has established meaningful connections between higher education and the actual demands of the industry, particularly within the Belt and Road framework. In recent years, the global textile and apparel sector has encountered significant challenges, including increasing environmental pressures, persistently low growth rates, high resource consumption in production, fragile supply chains, and the unavoidable shift toward digital transformation. At the same time, there is growing demand for green materials, circular reuse and recycling systems, transparent production tracking, and a larger pool of well-trained professionals. Against this background, WTUA has demonstrated its value by conducting annual training programs, offering scholarships to international students, establishing joint laboratories, organizing regular conferences, and hosting exhibitions that promote sustainable design while integrating traditional and contemporary approaches. These efforts have improved the quality of teaching and research across member universities while directly addressing key industry issues, such as shortages of skilled personnel, slow adoption of green technologies, and limited cross-border collaboration. By uniting institutions from both developed and developing countries, WTUA has created a balanced platform for sharing knowledge, experience, and resources, which is especially important for regions along the Belt and Road seeking to upgrade their textile industries. Looking forward, WTUA has strong potential to expand further by integrating digital tools and artificial intelligence more deeply into education and production processes, placing greater emphasis on plant-based and recycled materials, developing additional joint degree programs with mutual credit

recognition, and strengthening partnerships with industry associations and international organizations. As the global textile industry continues its transition toward sustainability, reduced carbon emissions, and intelligent manufacturing, networks such as WTUA will take on an even more important role in preparing future professionals and enabling companies to comply with stricter environmental and social standards. Ultimately, WTUA is far more than an academic network; it serves as a concrete model of international cooperation that enables the textile sector to confront future difficulties in a more coordinated and sustainable way. By leveraging China's substantial strengths in production and education alongside the diverse capabilities of partner universities worldwide, the alliance contributes to the creation of a global textile industry that is more resilient, equitable, and environmentally responsible. Its continued development and broader outreach will remain beneficial for both educational advancement and industry progress in the years to come.

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## DEFORMATION PROPERTIES OF TEXTURED MULTIFILAMENT POLYESTER YARNS

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### ABSTRACT

*In the process of textile production, the tensile force applied to the yarn should be controlled within the limits of elastic deformation. The maximum allowable load is determined by the creep limit.*

*The elastic limit and the creep limit were defined based on an analysis of the force–elongation behavior of multifilament textured polyester yarn.*

*Based on the obtained results, the relationship between the parameters at the creep limit and at the elastic limit was established.*

*The results may contribute to the development of a method for predicting the maximum yarn load in subsequent technological processes of textile production.*

**Keywords:** textured multifilament yarn, elastic limit, creep limit, tensile force, elongation

### INTRODUCTION

In the texturing process, fibers are reshaped, becoming curly and voluminous. In this way, synthetic filament fibers acquire some properties characteristic of natural fibers. In addition to increased bulk, textured yarn differs from filaments by significantly higher extensibility. The level of extensibility plays a major role in shaping the appearance and properties of the textured yarn, as well as the performance characteristics of the finished products. The voluminousness of textured yarn comes from the waviness of its individual filaments, which is often referred to as crimp. The wave shape of the yarn, or the pleat, and its mechanical properties depend on the texturing method and process parameters [1, 2, 3, 4, 5].

In the industry, conclusions about the quality of a yarn, in terms of its mechanical properties, are often drawn solely based on its breaking characteristics. This approach is not ideal. By analyzing the force and elongation values at the elastic and creep limits of textured multifilament PES yarns, a true picture is obtained of the loads that the yarn can withstand during technological processing into textile materials. This approach helps preserve the yarn's properties and, consequently, ensures the high quality of the finished product in accordance with the textile material design and standard requirements [6, 7].

### MATERIALS AND METHODS

The preparation of the experimental material was carried out under industrial conditions. Polyester multifilament yarn was produced on a stretch-friction texturing machine with a high-temperature heater FTF-15. Samples of textured PES yarn with fineness 167f36x1 dtex and 165f36x1 dtex were produced from POY PES multifilament with a fineness of 278f36x1 dtex, manufactured by TWD Fibers (Germany). The POY polyester filament (poly(ethylene terephthalate)) used in this study is partially oriented with a very low degree of crystallinity (less than 5%), so its properties can vary significantly depending on changes in the texturing process parameters.

Figure 1 shows the graph of the force-elongation dependence for the POY polyester multifilament.

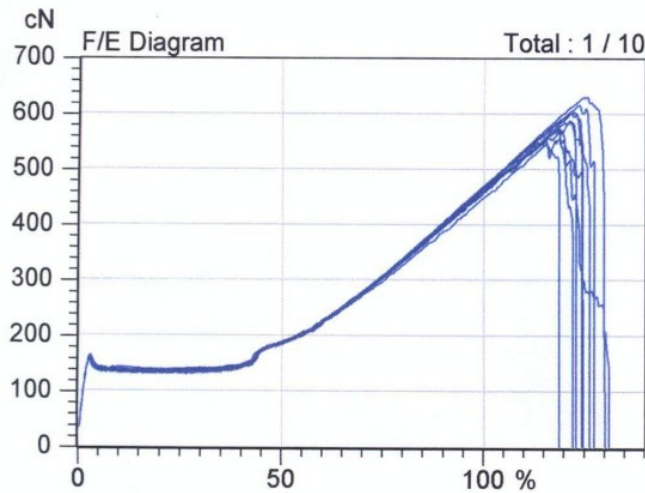


Figure 1. Force–elongation (F– $\epsilon$ ) curve of the POY PES multifilament

In the texturing process of the analyzed yarns (108 industrial samples), different primary heater temperatures (350 °C, 400 °C, and 450 °C) were applied while maintaining a constant secondary heater temperature (180 °C). The texturing was also performed at various speeds (500 m/min, 600 m/min, 700 m/min, 900 m/min, 1000 m/min, and 1100 m/min), with D/Y ratios of 2.15, 2.20, and 2.25, and draw ratios of 1.665 and 1.685.

The mechanical properties of the experimental material were determined using an automatic USTER TENSORAPID 4 dynamometer, in accordance with the SRPS EN ISO 2062 standard [8, 9]. Using the “USTER TENSORAPID” software, typical force–elongation curves were generated (Figure 2). The typical curves were represented as ninth-degree polynomial functions, with coefficients of determination around 0.999.

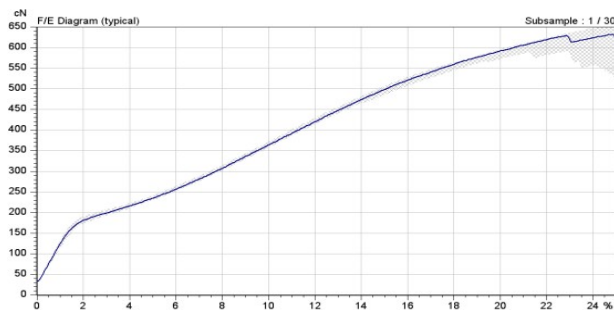


Figure 2. Typical force–elongation (F– $\epsilon$ ) curve of the PES multifilament yarn

The elastic limit defines the recommended allowable load for textured yarns at which no undesirable plastic deformation of the material occurs. The elastic limit of textured multifilament polyester yarns was determined by analyzing the behavior of the force–elongation function. By identifying the local maximum of the first derivative of the function, where the second derivative equals zero, the elastic limit was established, along with the corresponding force–elongation parameters at this limit.

Creep of textured multifilament yarns occurs when a load induces stress in the yarn above its elastic limit. It is determined by analyzing the force–elongation function and identifying the local minimum of the second derivative, i.e., the corresponding zero of the third derivative. At this point, the force and elongation values up to the creep limit are recorded. The creep limit of textured multifilament yarns represents the upper allowable load that the yarn can withstand in subsequent technological processes while maintaining acceptable properties for the designed characteristics of textile products.

## RESULTS AND DISCUSSION

Based on the obtained data, graphs were presented showing the relationship between the parameters at the elastic limit and the creep limit (Figures 3, 4, and 5). The value of the ratio of force to elongation is expressed in units of cN/mm.

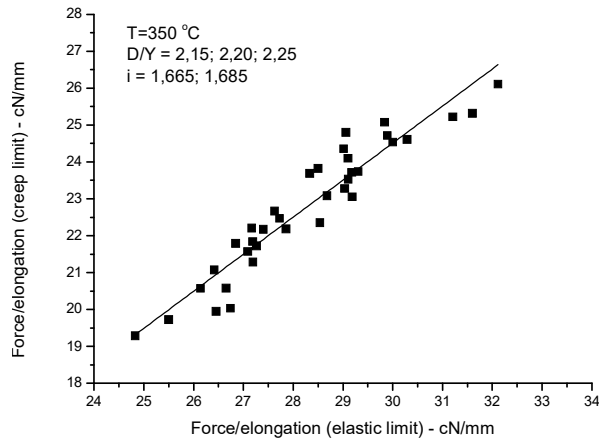


Figure 3. Parameter relationship  $F_2/\epsilon_{a2} = f(F_1/\epsilon_{a1})$   
 T = 350 °C, D/Y = 2,15; 2,20; 2,25, i = 1,665; 1,685

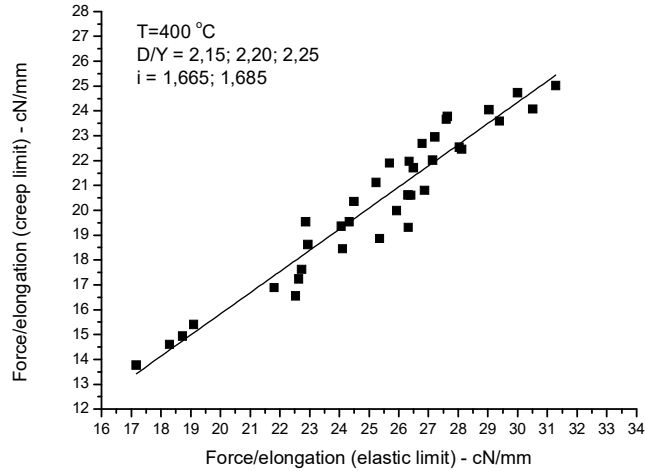


Figure 4. Parameter relationship  $F_2/\epsilon_{a2} = f(F_1/\epsilon_{a1})$   
 T = 400 °C, D/Y = 2,15; 2,20; 2,25, i = 1,665; 1,685

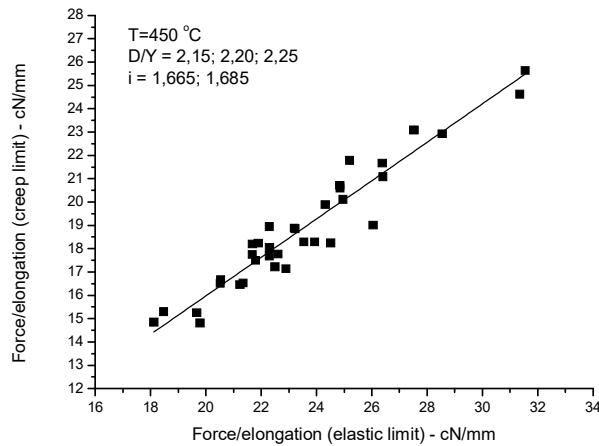


Figure 5. Parameter relationship  $F_2/\varepsilon_{a2} = f(F_1/\varepsilon_{a1})$   
 $T = 450 \text{ }^\circ\text{C}$ ,  $D/Y = 2,15; 2,20; 2,25$ ,  $i = 1,665; 1,685$

The relationship between the parameters at the creep limit ( $F_2/\varepsilon_{a2}$ ) and at the elastic limit ( $F_1/\varepsilon_{a1}$ ) can be described by regression equations, with coefficients given in Table 1.

Table 1. Regression equation coefficients

Function	$r^2$	$a$	Standard error	$b$	Standard error
$T=350 \text{ }^\circ\text{C}$ ; $D/Y=2,15, 2,20, 2,25$ ; $i=1,665, 1,685$					
$F_2/\varepsilon_{a2}=f(F_1/\varepsilon_{a1})$	0,899	-5,60	1,602	1,00	0,057
$T=400 \text{ }^\circ\text{C}$ ; $D/Y=2,15, 2,20, 2,25$ ; $i=1,665, 1,685$					
$F_2/\varepsilon_{a2}=f(F_1/\varepsilon_{a1})$	0,919	-1,19	1,084	0,85	0,042
$T=450 \text{ }^\circ\text{C}$ ; $D/Y=2,15, 2,20, 2,25$ ; $i=1,665, 1,685$					
$F_2/\varepsilon_{a2}=f(F_1/\varepsilon_{a1})$	0,918	-0,49	0,989	0,82	0,042

Based on the obtained relationships, the limiting load values of the analyzed yarns can be predicted.

## CONCLUSION

Understanding the deformation characteristics of textured multifilament PES yarn is very important for predicting its behavior during the production of textile materials, as well as for anticipating the performance of textile products during use.

By analyzing the force–elongation function, significant data can be obtained that indicate the properties of textured yarns, as well as the influence of individual production process parameters on these properties. The results show that there is a relationship between the parameters at the elastic and creep limits.

The analysis of the characteristics of textured yarns at the elastic and creep limits can contribute to the accurate prediction of the limiting loads to which textured yarns may be subjected in subsequent processing stages while preserving their properties. In addition, the parameters at the elastic and creep limits can be used to predict the characteristics of textile materials produced from these yarns.

## ACKNOWLEDGMENT:

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## DESIGN THINKING – SUSTAINABLE TRANSFORMATION OF THE TEXTILE INDUSTRY, COMPARATIVE ANALYSIS

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**ABSTRACT**

*The global textile industry has a major impact on the environment, contributing to significant CO<sub>2</sub> emissions and generating large amounts of waste. In parallel, custom tailoring operates on a small scale, offering personalized products with a low ecological impact. This article analyzes the application of Design Thinking methodology in both contexts, highlighting the methodological similarities and differences, as well as the implications for sustainability and innovation. Design Thinking, through empathy, problem definition, idea generation, prototyping and iterative testing, facilitates the development of innovative and efficient solutions. In the textile industry, this approach supports the integration of circular fashion concepts and supply chain optimization, but can be affected by the phenomenon of greenwashing. In custom tailoring, the method allows for quick adjustments, waste reduction and personalized products, with direct customer involvement. The comparative analysis shows that the industry can learn from tailoring about personalization and social responsibility, and tailoring can adopt industrial technologies and practices. Adopting Design Thinking thus contributes to the sustainable transformation of the entire sector, providing tangible benefits for both the environment and innovation and operational efficiency.*

**Key words :** Design Thinking, textile industry, sustainability, Greenwashing, custom tailoring

**INTRODUCTION**

The textile industry is one of the most dynamic economic sectors globally, but also one of the most polluting. Recent estimates indicate that it contributes around 10% to global CO<sub>2</sub> emissions and generates millions of tonnes of textile waste annually. The production of a single shirt requires, on average, 2,700 litres of water, underlining the urgent need for sustainable practices. <sup>1</sup>Legislative pressures, such as the European Green Deal (2019) and EU directives on waste management <sup>2</sup>, combine with growing consumer expectations for ethical and transparent products <sup>3</sup>, leading companies to adopt sustainable and innovative practices.



<sup>1</sup>Kim JO (1999). *Dynamic Moisture Vapor Transfer through Textiles: Part III* . Textile Research Journal, 69(3), p.193–202.

<sup>2</sup>European Commission (2019). *European Green Deal*, Official Document.

<sup>3</sup>Brown T. (2009). *Change by Design* , Harper Business, New York, pp. 21–45.

<sup>4</sup> <https://www.fae.ro/ifn/curs/modul-3-solul-si-economia-circulara/> accessed 09.11.2025

*Figure 1. The circular economy model in the European Parliament's vision*

In parallel, the digitalization and customization of production create opportunities for tailoring to order, where immediate feedback and adaptability allow for the reduction of waste. In this context, Design Thinking is emerging as a methodology capable of simultaneously responding to the needs of large companies and micro-enterprises, facilitating sustainable innovation through empathy, rapid prototyping and iterative testing <sup>5</sup>.

The differences in scale and complexity between the global textile industry and custom tailoring necessitate a comparative analysis that highlights how Design Thinking principles can be effectively applied in different contexts. This analysis examines how each scenario integrates sustainability and innovation, identifying the challenges and advantages specific to each scale of production.

The objective of the paper is to highlight the mutual learnings between large-scale industries and micro-businesses, demonstrating that the universal principles of Design Thinking can be adapted to increase efficiency, sustainability and customer experience.

### **THEORETICAL FOUNDATIONS / THEORETICAL FRAMEWORK**

To understand the applicability of **Design Thinking methodology** in the context of the textile industry and custom tailoring, it is essential to clarify the key concepts used in this analysis. Design Thinking is a user-centered innovation methodology that combines empathy, creative thinking and rational analysis to generate effective solutions to complex problems <sup>6</sup>. This involves going through specific steps:

1. **empathize** – deep understanding of the user;
2. **define (define the problem)** – clear formulation of the challenge;
3. **ideate (ideate / generate ideas)** – creative development of several possible solutions;
4. **prototype** – transforming ideas into tangible prototypes;
5. **test (iterative testing)** – validation and continuous improvement through iterative feedback <sup>7</sup>.

By applying it, companies can design products and services that better meet user needs, reduce waste and optimize the resources involved in the production process <sup>8</sup>. In the textile industry, this methodology facilitates the integration of sustainability into supply chains, the development of recycled materials and the creation of innovative solutions, adapted to both large-scale production and micro-production of tailor-made clothing.

**Greenwashing** is a concept associated with deceptive marketing practices, whereby a company creates a false impression of environmental responsibility <sup>9</sup>. In the textile industry, this process can manifest itself by promoting “green” collections without verifiable certifications, using vague terms such as “natural” or “sustainable”, selectively reporting information, or a discrepancy between the promoted image and actual production practices. Consequently, greenwashing can damage consumer trust and slow down real progress towards sustainability <sup>10</sup>.

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<sup>5</sup>Gunawan S., Suharyono S., Sari D. (2023). *Green Entrepreneurship in Eco-Fashion*. Journal of Manajemen Indonesia, 23(4), pp. 287–300.

<sup>6</sup>Brown, T. (2009). *Change by Design*. Harper Business, New York, pp. 25–30

<sup>7</sup>Gunawan, S., Suharyono, S., Sari, D. (2023). *Green Entrepreneurship in Eco-Fashion*, Jurnal Manajemen Indonesia, 23(4), p. 287–300.

<sup>8</sup>Liedtka, J., & Ogilvie, T. (2011). *Designing for Growth*. Columbia University Press, New York, pp. 40–45

<sup>9</sup>Delmas, MA, & Burbano, VC (2011). *The Drivers of Greenwashing*. California Management Review, 54(1), pp. 64–87.

<sup>10</sup>Greenpeace (2020). *Fashion at the Crossroads*. Greenpeace International, Amsterdam, pp. 16–20.

There is an important connection between Design Thinking and combating greenwashing, as the methodology promotes rigorous research, prototyping, and transparent product testing. Companies that adopt this approach can develop real and measurable solutions to reduce environmental impact, avoiding promoting green practices only at the image level. Thus, Design Thinking not only stimulates innovation, but also ensures the authenticity of sustainable approaches.

### **Design Thinking in the textile industry**

On an industrial scale, the application of **Design Thinking** focuses on managing the complexity of supply chains and optimizing processes for high-volume production. Large companies need to coordinate production across factories, warehouses, and distributors while maintaining high standards of quality and sustainability.

In this context, the Design Thinking methodology facilitates the development of innovative products through iterative stages: researching consumer needs, clearly defining challenges, generating ideas, prototyping materials and testing products before large-scale launch. For example, large fashion brands have started to implement **circular fashion concepts**, which involve the reuse and recycling of textile fibers, as well as the collection of old clothes to be transformed into new materials <sup>11</sup>. This approach contributes to reducing waste and optimizing production costs.

Examples of brands that implement circular fashion practices and contribute to the sustainable transformation of the industry:

- *Patagonia* is recognized for its "Worn Wear" program, through which customers can return old clothing for reuse, repair or recycling, thus helping to reduce waste and extend the life cycle of products.



*Figure 2 – Patagonia’s “Worn Wear” program: customer returning clothes for recycling and reuse.*

- *H&M*, through its “Conscious Exclusive” collection, uses recycled fibers and sustainable materials — for example, ECONYL® (regenerated nylon from fishing nets) or Naia™ Renew (certified wood fiber + recycled plastic).



<sup>11</sup>Teixeira, B., Carvalho, F., & Dias, A. (2023). *Circular Design Strategies in the Textile Industry*. Journal of Cleaner Production, 415, pp. 137–149.

<sup>12</sup> <https://www.patagonia.com/trade-in/?utm>, accessed 09.11.2025

*Figure 3 – H&M Conscious Exclusive 2018 collection: outfits made from sustainable materials, including recycled silver and ECONYL®*

- *Stella McCartney* is a designer who promotes circular fashion and sustainable materials innovation, contributing to the responsible transformation of the textile industry. At the COP28 exhibition, the brand presents bio-based alternatives to leather and plastic, highlighting its ongoing research and commitment to circular fashion.



*Figure 4 Stella McCartney (2024). Sustainable Market: Innovating Tomorrow's Solutions , COP28*

However, challenges remain significant. The risk of **greenwashing** is high as some companies promote “eco” collections without providing full transparency or verifiable evidence of environmental impact. For example:

- **Zara/Inditex** has been criticized for its "Join Life" collections, promoted as sustainable but without full transparency <sup>15</sup>.
- **Forever 21** uses "eco-friendly" labels without concrete evidence <sup>16</sup>.
- **Shein** has been accused of green marketing, even though it produces fast fashion with massive waste <sup>17</sup>.

In addition, implementing sustainable solutions on a large scale can increase costs and limit process flexibility, which requires careful planning and continuous adaptation of strategies. At the industrial level, Design Thinking involves collaboration between designers, engineers and sustainability specialists to develop innovative and environmentally and economically efficient solutions. Rapid prototyping and pilot batch testing allow the feasibility of ideas to be assessed before full production, reducing waste and optimising costs. Innovative materials, such as recycled fibres or smart textiles, can be tested in this process, and workflow diagrams highlight the stages of research, prototyping and testing, demonstrating the integration of sustainability and innovation into industrial practice.

### **Design Thinking in custom tailoring**

In custom tailoring workshops, Design Thinking is applied on a small scale, but with a direct impact on the product and the customer experience. Unlike industrial production, the process focuses on the individual needs of each customer, allowing for detailed customization of the clothes. The stages of the methodology are similar to those in large industry, but are applied in a more flexible and adaptable framework. The process begins with empathy, through direct discussions with the customer, precise

<sup>13</sup> <https://hmgroupp.com/news/hm-conscious-exclusive-2018-brings-together-powerful-femininity-and-sustainable-fashion-innovation-with-recycled-silver-and-econyl/?utm>, accessed 09.11.2025

<sup>14</sup> [https://www.stellamccartney.com/us/en/COP28-UN-climate-conference-stellas-sustainable-market.html?utm\\_source=chatgpt.com](https://www.stellamccartney.com/us/en/COP28-UN-climate-conference-stellas-sustainable-market.html?utm_source=chatgpt.com), accessed 09.11.2025

<sup>15</sup> Greenpeace (2020). *Fashion at the Crossroads*. Greenpeace International, pp. 10–15

<sup>16</sup> Ibid., pp. 16–20

<sup>17</sup> Forbes (2022). *The Environmental Cost of Fast Fashion Brands*. Forbes.com

measurements and observations of how the clothes will be used. This is followed by problem definition, in which the requirements regarding the type of material, cut, functionality and durability of the product are clarified.

In the ideation stage (Ideas), designers can explore sustainable materials, such as recycled fibers, ecologically treated natural fibers, or smart textiles. It is the creative phase of the Design Thinking process, in which the team generates as many possible solutions to the previously identified problem, without initially evaluating the feasibility of the ideas . Prototyping is done quickly by creating samples or prototypes presented to the client, and testing involves immediately adjusting the design based on the feedback received. This approach minimizes waste of materials and time, increasing customer satisfaction and creating unique products, adapted to real needs.

The advantages of this method include flexibility, the ability to quickly experiment with innovative solutions, and the natural integration of sustainability into the production process. On the other hand, the challenges include limited resources, higher costs per unit, and longer lead times for each individual product.

Examples of workshops or designers that practice sustainable tailoring include :

- Orlando Cristian Hegheduş, known by his stage name *ONEK*, combines his passion for tailoring with the creativity of recycling, transforming second-hand textiles into unique streetwear pieces, thus promoting sustainable fashion and creative reuse.<sup>18</sup>
- *OMRA* (founded by Chrisa Dobreanu), is the first sustainable fashion brand in Romania, established in 2016 in Bucharest, focused on fabric selection, attention to detail, the use of high-quality tailoring and manufacturing techniques. All OMRA products are ethically manufactured in Romania.<sup>19</sup>
- *Verlinne* is a sustainable brand because it prioritizes quality materials, avoids toxic substances, minimizes waste and plastic, ensures fair working conditions, and promotes transparency and integrity in its relationship with customers.<sup>20</sup>
- *3WLABEL*, the first fashion brand made in RO that uses unused stock from garment factories to produce clothing. The name 3WLABEL reflects the essence of the brand, transforming the three "R" concepts - Reuse, Redesign and Return - into three "W" directions: Waste to Resource, Wearables and Women Empowerment.<sup>21</sup>

The advantages of this method include flexibility, the possibility of rapid experimentation, and the natural integration of sustainability, while the main challenges are the higher costs per unit and the time required for each product.

Although custom tailoring is perceived as a form of sustainable production, the phenomenon of *greenwashing* can also occur here, when the terms “eco” or “ethical” are used without clear evidence. Lack of transparency regarding the provenance of materials or the partial use of sustainable resources can create a false image of ecological responsibility. Therefore, small workshops must ensure honest and documented communication to avoid turning sustainability into a simple marketing tool.

### Comparative analysis: industry vs. custom tailoring

appearance	Textile industry	Custom tailoring
Scale and impact	Global production, complex chains	Micro-production, immediate feedback
Empathy	Market research, surveys,	Direct interaction with the

<sup>18</sup> <https://buletindetimisoara.ro/timisoara-un-cuncousto-designer-onek-transforma-hainele-second-hand-in-arta-urbana-i-se-spune-croiturul-de-la-glovo-deoarece-a-lucrat-ca-si-curier-expert/?utm> accessed 09.11.2025

<sup>19</sup> <https://luxury.ro/02/omra-conscious-sustainable-creative-fashion-design-brand/?utm> , accessed 09.11.2025

<sup>20</sup> <https://verlinne.com/?utm> , accessed 09.11.2025

<sup>21</sup> <https://ralucaharabagiu.com/3wlabel-brand-ro-upcycled/?utm> , accessed 09.11.2025

	sample testing	customer
Prototyping	Pilot batch testing	Individual samples
Sustainability	Circular fashion, recycling, risk of greenwashing	Local production, minimal waste
Innovation	Limited by cost and volume	High, due to flexibility

This table highlights the differences in scale, complexity and impact between the two contexts, but also underlines the common principles of Design Thinking – empathy, problem definition, ideation, prototyping and testing – applicable in a manner adapted to each context.

The comparative analysis highlights both methodological convergences and structural differences between the large-scale textile industry and custom tailoring. The data presented in the table is based on my own observations, specialized literature and recent studies on Design Thinking and sustainability in the fashion industry.

### CONCLUSIONS AND RECOMMENDATIONS

Design Thinking is a flexible methodology, applicable both in the large-scale textile industry and in custom tailoring, which supports sustainability and combating greenwashing. In small workshops it allows for customized products with low environmental impact, and in industrial production it optimizes processes and reduces waste.

It is recommended to integrate Design Thinking into the organizational culture, rapid prototyping, continuous testing and use of customer feedback for constant improvement.

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## **VIRTUAL THREE-DIMENSIONAL SIMULATION AND COMFORT ASSESSMENT OF FOOTBALL JERSEYS USING OPTITEX**

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### **ABSTRACT**

*Tree-dimensional (3D) virtual prototyping has become an essential method in garment design which allows the realistic visualisation of fit, comfort, and fabric behaviour prior to production. This paper focuses on virtual simulation and comfort assessment of football jerseys using OptiTex software. The mechanical and physical parameters of six knitted fabrics were used to make the simulations: four conventional and two functional, which have phase-change materials (PCM) incorporated. These parameters were acquired from the KES-FB system and processed in the Fabric Editor tool. A virtual prototype of a football jersey was developed, and comfort was evaluated by the Tension Map tool. The obtained results of maximum tension values for functional knitted fabrics were 12.51 gf·cm<sup>-1</sup> and 8.81 gf·cm<sup>-1</sup> for FJ-5 and FJ-6, respectively, indicating a closer fit to the mannequin body. Conventional knitted fabrics showed lower tension values in the range from 3.76 gf·cm<sup>-1</sup> to 5.40 gf·cm<sup>-1</sup> which indicated better comfort. The areas that showed the highest values of tension are the shoulder, chest, collar, and sleeve junction points. These findings confirm that 3D simulation gives an understanding of the garment fit and feel to optimise sportswear design and minimise real-world prototypes required to be made.*

**Key words:** 3D virtual simulation, football jersey, knitted fabrics, comfort assessment, OptiTex.

### **INTRODUCTION**

Three-dimensional (3D) clothing design and simulation programs have become indispensable in the textile industry in recent years. Through digital prototyping, the designer can perform the entire design and testing process in a virtual environment. This reduces the number of physical prototypes, saves time and material resources, while also ensuring a higher level of quality control.

Specialised CAD software (e.g. OptiTex, Lectra, Clo ect) allows the simulation of clothing behaviour on a virtual mannequin in static and dynamic conditions. It is possible to analyse parameters such as fit, material drape, dimensions of cut parts and stress distribution during movement. Also, the body dimensions of the virtual mannequin can be adjusted to different users, which provides a more realistic assessment of the design and functionality of the product. Virtual simulation is now also used for commercial purposes, as a substitute for two-dimensional photographs when presenting the product to the end user (Aydođdu et al., 2007; Chowdhury et al., 2012; Jariyapunya & Sutdaen, 2012).

Based on previous research, it can be concluded that OptiTex has proven to be a reliable tool for analysing the comfort of clothing items, especially thanks to the possibility of determining tension values using the Tension Map tool. This software enables a realistic simulation of the behaviour of fabrics and knitted fabrics, thus achieving a high degree of correspondence between virtual and real prototypes (Mahnić et al., 2017; Song & Ashdown, 2015). The results of these and similar studies indicate that 3D simulations represent a reliable and efficient method in the development of sportswear. They enable more precise prediction of material behaviour, better understanding of the interaction of clothing and the body and reduce the risk of manufacturing errors. Therefore, digital prototypes are becoming the modern standard in the design of sportswear that requires a precise fit, high functionality and aesthetic value.

In this paper, a 3D simulation of a football jersey was performed using parameters of six different knitted fabrics, showing how the design would look on a person. Based on these simulations, the Tension Map option was used for comfort assessment of football jerseys.

## MATERIALS AND METHODS

To create a 3D computer simulation of a football jersey in OptiTex software, it was necessary to determine the mechanical and physical properties of the knitted fabrics used for garment production. The parameters of used knitted fabrics are presented in Table 1.

*Table 1: Parameters of knitted fabrics*

Knitted fabric code	Knit structure	Fiber composition	Yarn count $T_t$ [tex]	Total density $D_t$ [cm <sup>2</sup> ]	Thickness $h$ [mm]	Surface mass $W$ [g·m <sup>-2</sup> ]
1	Interlock1:1	PES	7.40	171.15	0.382	127.49
2	Rib knit (honeycomb)	PES	7.40	211.93	0.497	123.87
3	Rib knit 1:1	PES	11.11	279.00	0.330	134.50
4	Plain Jersey	Co	19.46	315.00	0.432	158.32
5*	Pique (Mesh)	80% PA 20% EL	8.20 2.20	1260.00	0.518	177.37
6*	Right-left rib (Perlfang)	86% PA 14% EL	19.38 2.20	207.00	0.474	196.57

\*Knitted fabrics containing phase change materials.

The mechanical properties of the knitted fabrics were measured using the KES-FB system under laboratory conditions (temperature  $20 \pm 2$  °C, relative humidity  $65 \pm 5\%$ ). The following conditions were obtained:

- Tensile properties – Elongation  $EMT$  [%],
- Bending properties – Bending stiffness  $B$  [cN·cm<sup>2</sup>·cm<sup>-1</sup>],
- Shear properties – Share rigidity  $G$  [cN·cm<sup>-1</sup>·st<sup>-1</sup>],
- Surface properties – Coefficient of surface friction  $MIU$  [/] measured on the reverse side of knitted fabrics.

Three measurements were performed for each sample and the mean values are presented in the Table 2.

*Table 2: KES parameters of knitted fabrics*

Knitted fabric code	$EMT$ [%]		$B$ [cN·cm <sup>2</sup> ·cm <sup>-1</sup> ]		$G$ [cN·cm <sup>-1</sup> ·st <sup>-1</sup> ]		$MIU$ [/]	
	Wale	Course	Wale	Course	Wale	Course	Wale	Course
1	16.06	36.36	0.0072	0.0034	0.55	0.54	0.157	0.243
2	17.10	30.79	0.0132	0.0065	0.82	0.81	0.165	0.234
3	13.54	39.16	0.0074	0.0028	0.74	0.68	0.283	0.207
4	17.10	29.55	0.0065	0.0103	0.69	0.66	0.215	0.186
5*	22.34	26.77	0.0077	0.0108	0.34	0.34	0.150	0.212
6*	53.11	50.19	0.0084	0.0089	0.16	0.23	0.292	0.216

The mechanical (Table 2) and physical properties (surface mass and thickness) of the knitted fabric shown in Table 1 were used as input parameters for the simulation. These values were converted using Fabric Editor into the parameters required for 3D simulation in OptiTex. Based on the data obtained, a virtual prototype of a football jersey was created in OptiTex software (Figure 1).

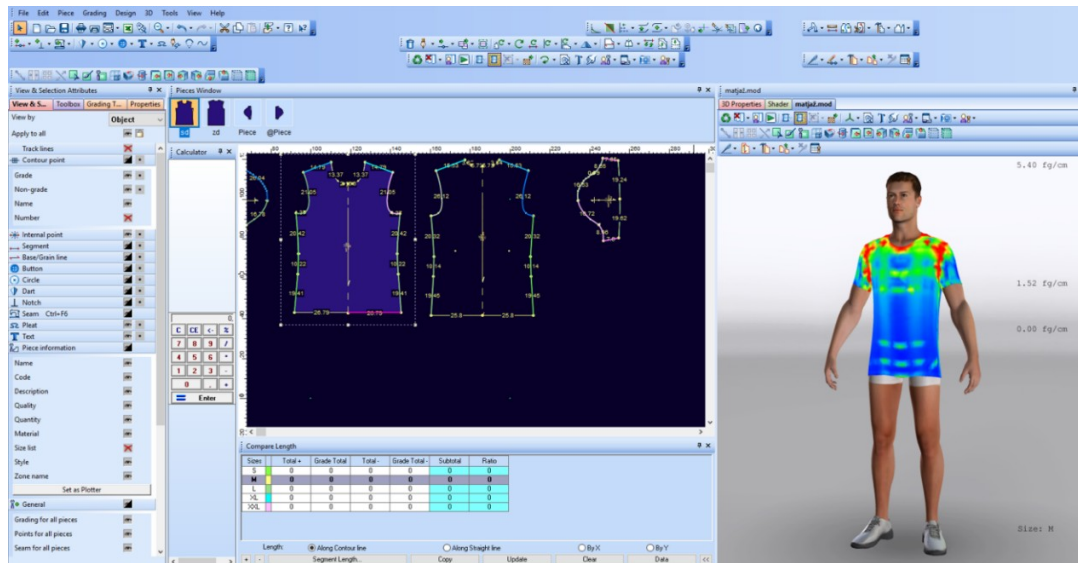


Figure 1: Interface of the Tension Map tool in OptiTex with the imported garment pattern

The jerseys are coded with FJ (football jersey) followed by a number that corresponds to the specific knitted fabric whose parameters were used for the simulation.

The Tension Map tool was used to evaluate fit and comfort. This tool provides a colour-coded visualisation of tension, stretch and distance between the garment and the body of the virtual mannequin. Higher values (warm colours: red, orange and yellow) indicate greater tension, while lower values (cool colours: green and blue) indicate lower garment pressure (Figure 2).

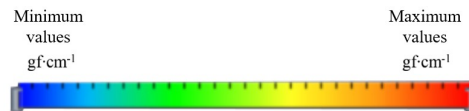


Figure 2: Colour scale in the Tension Map tool

Virtual mannequin in a static position was used for testing the comfort of a football jersey. The aim of the comfort analysis in this paper was to identify, through a focus on the upper part of the body, critical points where discomfort can be felt while wearing the jersey.

## RESULTS

The maximum tension values (in  $\text{gf}\cdot\text{cm}^{-1}$ ) obtained via the Tension map tool in OptiTex software are presented in Figure 3.

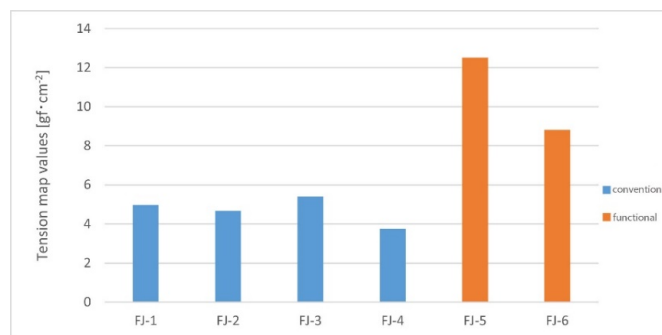
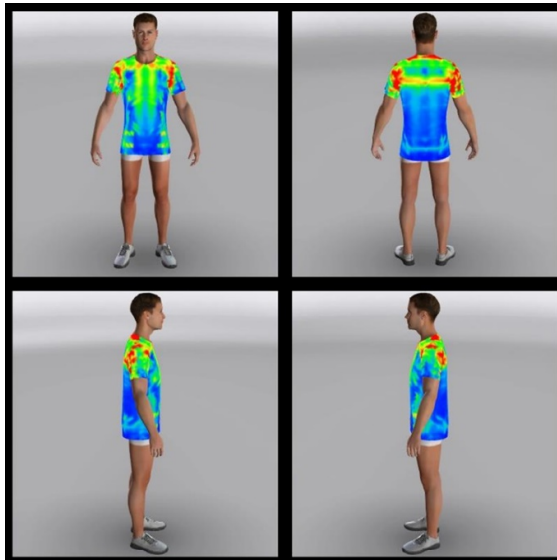


Figure 3: Comfort assessment results of football jerseys obtained through the Tension Map tool

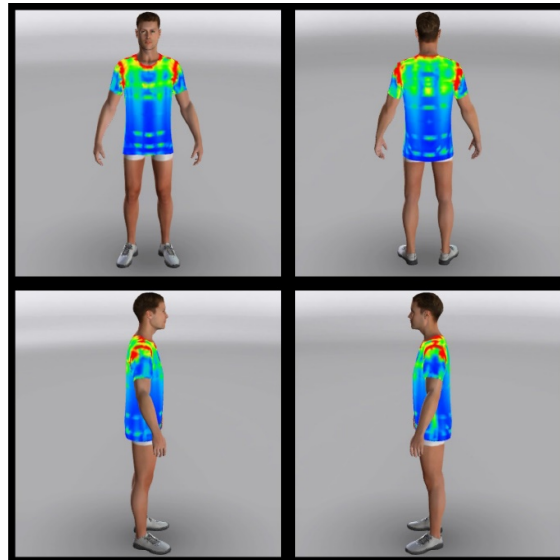
The highest Tension Map value was recorded for the football jersey labelled FJ-5, while the lowest for FJ-4.

Based on the results obtained, it is evident that higher values were recorded for football jerseys made of functional knitted fabrics, namely  $12.51 \text{ gf}\cdot\text{cm}^{-1}$  (FJ-6) and  $8.81 \text{ gf}\cdot\text{cm}^{-1}$  (FJ-5), while for conventional knitted fabrics these values range from  $3.76 \text{ gf}\cdot\text{cm}^{-1}$  to  $5.40 \text{ gf}\cdot\text{cm}^{-1}$ . These results indicate that football jerseys made of functional knitted fabrics create a closer fit (exert more pressure) against the body of the virtual mannequin.

Figures 4 to 9 show the Tension map of simulated football jerseys.



*Figure 4: Tension map of the simulated football jersey FJ-1*



*Figure 5: Tension map of the simulated football jersey FJ-2*

Figure 4 shows the Tension Map of the simulated FJ-1 jersey, for which the mechanical and physical parameters of the PES knitted fabric in an interlock pattern were used. The front of the football jersey is dominated by blue and green. The back of the jersey - the upper half is dominated by green, the shoulder blades are orange (suggesting a certain tension of the knitted fabric), while the lower part is dominated by blue (indicating the greatest distance between the skin and the garment). Small areas of red are visible at the points where the sleeves connect to the front of the jersey. More pronounced red areas are visible at the points where the sleeves connect to the back of the football jersey, as well as at the collar on the back. Based on the simulation, it can be concluded that the realised football jersey model would fit closely in the chest and upper back area.

The Tension Map of the simulated model of the FJ-2 football jersey is shown in Figure 5. The football jersey is dominated by blue and green colours, with red visible at the points where the sleeves connect to the front and back of the jersey, as well as on the collar. Based on the low and moderate tension values obtained via simulation, it can be concluded that this jersey would be suitable for high-performance sportswear.

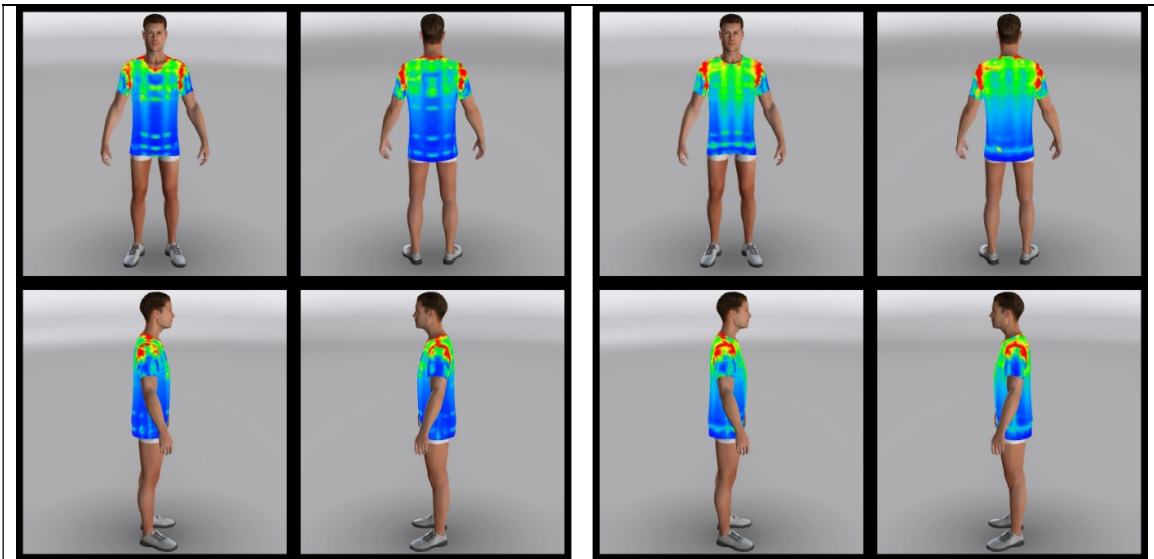


Figure 6: Tension map of the simulated football jersey FJ-3

Figure 7: Tension map of the simulated football jersey FJ-4

Figure 6 shows the Tension map for simulated football jersey FJ-3, which was created using parameters of PES knitted fabric in Rib knit 1:1. Red colour is visible at the points where the sleeves connect to the front and back of the football jersey and the sleeve parts, as well as on some parts of the collar. The blue colour dominates on the front and back of the football jersey, while the green colour is also visible on the top part (front and back).

Figure 7 presents the Tension Map of the simulated FJ-4 football jersey (parameters of the Co knitted fabric in plain jersey were used for the simulation). The blue colour dominates on the front of the football jersey, while the green colour is also present on the top part (chest) and around the hips. On the back of the football jersey, in the upper part, there is a combination of blue and green colours, and in the lower part of the football jersey there is only blue colour. At the point where the sleeves connect to the front and back, the red colour with a little orange is pronounced. The red colour is also visible on the back of the collar.

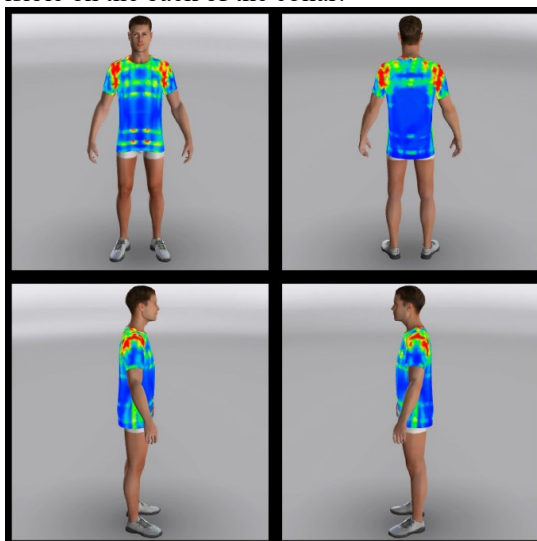


Figure 8: Tension map of the simulated football jersey FJ-5

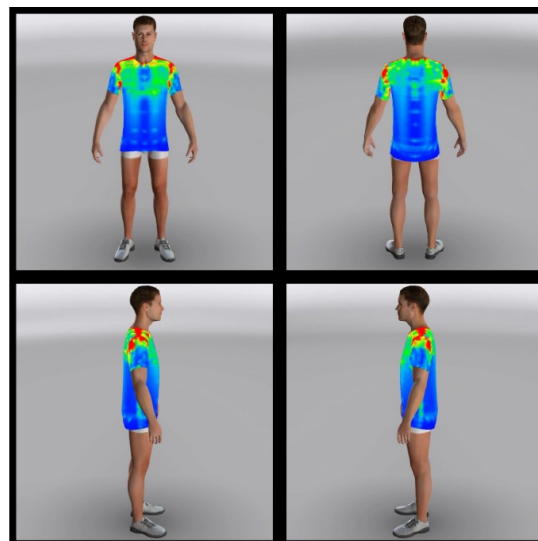


Figure 9: Tension map of the simulated football jersey FJ-6

Figure 8 shows a Tension map of the simulated FJ-5 jersey (the simulation was created using parameters of the functional Outlast knitted fabric). The front of the football jersey is dominated by blue, while the upper part is green in the form of three stripes positioned across the chest. There are two green stripes around the hips and waist. The seams (on the sides) are green and yellow. The red colour is dominant at the point where the sleeves connect to the front and back. The red colour is also visible on the back of the football jersey, right next to the sleeves.

A Tension map of the simulated FJ-6 football jersey (made based on parameters of the functional knitted fabrics in Perlfang knit pattern) is presented in Figure 9. The front of the football jersey is dominated by blue with green areas on the most protruding parts of the chest, while the back of the jersey is dominated by blue with extremely small green areas. Small red areas are arranged around the collar and at the junction of the sleeves and the front part, while larger red areas are arranged at the junction of the sleeves and the back of the football jersey.

The simulation results (Figure 1) show a direct connection between the mechanical and physical properties of the knitted fabric and the fit of the jersey. Jerseys simulated from conventional knitted fabrics showed the least strain on the body, indicating their superior comfort compared to functional knitted fabrics.

## CONCLUSION

In this paper, OptiTex software was used for the creation of 3D virtual stimulation, and the Tension map tool was used for assessing the comfort of football jerseys. The jerseys simulated using mechanical and physical parameters of conventional knitted fabrics generally showed lower tensile values, indicating improved comfort and looser fit. In contrast, jerseys based on functional knitted fabrics resulted in simulated jerseys with higher tension values, indicating a closer fit.

The most comfortable is the FJ-4 jersey (for the simulation of which the parameters of the conventional knitted fabric were used), which is confirmed by the lowest Tension map values. The highest values were recorded for the FJ-5 jersey, simulated using the parameters of the functional knitted fabric. The Tension Map tool has successfully identified the critical tension zones (shoulders, chest, collar and sleeve junctions), providing valuable information for garment design optimisation.

Future studies will focus on investigating the influence of sublimation printing on the comfort and fit of high-performance sportswear. This will be achieved by using a 3D simulation tool and validating results by comparison with physical prototypes.

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# **PIEZOELECTRIC FIBROUS STRUCTURED NANOGENERATORS: STATE-OF-THE-ART AND FUTURE CHALLENGES**

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## **ABSTRACT:**

*In recent years, next-generation of wearable electronics has been integrated into conventional textiles using the advanced nanogenerator technology. Textile structures are inherently flexible, making them well-suited for wearable applications although there are still some major concerns regarding to these issues. However, their electrical performance as nanogenerators is significantly limited when used without any modifications. To address this limitation and challenges, this talk is aimed to address provide different strategies to fabricate textiles-based piezoelectric and triboelectric nanogenerators. The speech covers the fundamentals of piezoelectricity and triboelectricity, the working principles of nanogenerators, state-of-the-art, challenges and future outlines.*

*Furthermore, it provides a detailed discussion of nanocomposite textiles in various forms, such as fibers or yarns, fabrics, and electrospun nanofibrous webs, which are employed in piezoelectric and triboelectric nanogenerators. An special focus is considered to provide a deep insight to the application of Advanced Fibrous Materials in these applications. Nano fibrous materials have numerous possible commercial and technological applications including use in electronic. In the last few decades, there has been significant progress in nanostructures with nanoscale and molecular scale properties that can satisfy the demands of the 21st century, for example, carbon nanotubes, inorganic semiconducting and metallic nanotubes/wires, conjugated polymer nanofibers/tubes, etc.*

*These nanostructures have a deep impact on both fundamental research and potential applications in nanoelectronics or molecular electronics, nano devices and systems, nanocomposite materials, bionanotechnology and medicine.*

## **DISCUSSIONS AND SUMMARY**

Textile-based generators or woven/knitted structural generators are ideal for wearable devices intended for practical applications. Woven fabrics have high durability and wear resistance, keep their shape well, and are often made into shirts, suits, denims, jackets, etc.

Knitted fabrics have high air permeability, and are usually made into T-shirts, underwear, sportswear, socks, etc [1]. Comfort has been an important aspect in the assessment of the performance of the textiles [2].

The characteristics of comfort are the breathability, skin sensitivity, washability, and moisture permeability of the fabric. These parameters are being used to evaluate the standard of wearability for a given material [1, 3]. It is essential to maintain fabric comfort and breathability when introducing electrode materials to fabric geometric TENGs.

Furthermore, in the case of fabric geometric TENGs, the electrodes must be compatible with the softness, breathability, and comfort of the fabric. The insufficient bonding strength between the electrodes and fabric can impact charge collection and subsequently affect the output of TENGs [4]. Metallic foils have the high electrical conductivity, but they are prone to failure after cyclic bending and they are not breathable or stretchable. Alternatively, metallic nanoparticles or nanowires can be

introduced on the textile as the electrodes. Other techniques are utilizing carbonaceous materials (carbon nanotubes, carbon nanoparticles, carbon fibers, graphene) and conductive polymers to fabricate electrodes [5-8].

Fabric structure is also one of the significant factors in the comfort assessment. For example, it is mandatory to consider the inherent volume of 3D structures and their integration into fabrics to address the challenges related to resilience and other associated factors [1,4]. Increasing the comfort of a wearable generator is generally accompanied by a reduction in the amount of energy harvested. A good balance between the comfort and actual output needs must be further explored [1]. In the case of chemical modification, the substrate will be covered with a layer. Zhang et al. ascertained that the fluorocarbon plasma treatment of the surface of PDMS increased the maximum energy area density of the TENG by 278% [9].

The coverage of the coating also eventuates in a loss of air permeability for woven fabrics. The air permeability of coated/knitted fabrics will also decrease, but not as severely as for woven fabrics. The thickness of the coating affects the breathability of the fabric, and the adhesion condition of the coating to the fabric substrate determines the washability of the fabric. Attentions need to be paid to the breathability of the fabric and the adhesion of the coating when designing the wearable TENG [1]. It was transpired from the results of other studies that the electrical properties of TENGs are influenced by various factors, including the humidity, thickness, temperature, and contact force.

High temperatures can reduce the charge on the surface of friction material. Moisture in the environment tends to be adsorbed onto the surface of the friction material, impeding charge transfer between the contacting surfaces. TENGs with a larger thickness also deliver a high area power density. Furthermore, the output power increases with increasing the contact force [5,10]. As aforementioned, Direct connection between the energy harvester and energy storage device is not possible and the energy management unit is necessary. Adequate attention must be given to the design of power management circuits.

Diodes direct the flow of electricity. Architectures with modified active diodes are good solutions when the input signals have high amplitude values. When the amplitude of the input voltage is higher than the output DC voltage, active diodes allow optimizing the conduction phase while reducing current leakage, thus improving the power transfer to the load. Moreover, an auxiliary boosting system, such as charge pump is requisite for charge boosting and acquiring maximum energy output [11].

Basically, there is an intrinsic capacitor inside the TENG that makes it high impedance, high voltage, and low current. Since this intrinsic capacitor is very low, the charging efficiency for the energy storage unit would be very low. Hence, there is a need for a correct impedance match between the TENG and the energy conditioning circuit [1]. It is clear that the use of machine learning algorithms is an inevitable trend in the future. Here, the most significant contribution of ML is to increase the performance of wearable systems by taking advantage of the model's self-learning ability. The difference in the results of each algorithm depends mainly on the characteristics of the collected data from the flexible sensors [12].

Environmental sustainability is also a common problem because some triboelectric materials can be difficult to degrade naturally and can present considerable ecological impact. Many research studies related to TENGs based on natural materials have been reported. natural materials used in TENGs exhibited good properties, such as the low cost and good degradability. Therefore, individuals must try to use TENGs based on natural materials for large scale industrial production that will effectively decrease pollution and hazards caused by metal and hardly degradable plastic materials.

## **CONCLUSION AND FUTURE CHALLENGES:**

Energy harvesting requires a device for converting surrounding energy into a usable form of energy, such as electrical energy. Among various types of energy harvesters, a triboelectric nanogenerator has excellent energy converting efficiency and applicability to self-powered sensors. In particular, fabric based TENGs are highly compatible with human body and skin in term of flexibility, stretchability, and texture. Fabric-based TENGs have also great potential due to dense internal fiber-to-fiber mechanical interaction.

As a result, they are promising candidates for wearable electronic products. With respect to the structure and geometric of the fabrics, fabric-based TENGs can be classified into two main groups; woven fabric-based TENGs and knitted fabric-based TENGs. Fabrics can be used directly as a triboelectric material or serve as substrates for other materials that possess better triboelectric properties.

In some examples of fabric-based TENGs, the fabric acted as the substrate. That is, it provided mechanical support and another material with better triboelectric properties was attached to the textile. Because of the material choice, the performance of the T-TENG could be greatly enhanced.

Most examples of fabric-based TENGs worked by contact separation mode because of the high-power output, nature of human motion, and the simplicity of the fabrication. Owing to some traits of electrical output of TENGs, such as high voltage, large impedance, and low current, the electrical power generated by TENGs is hard to be transferred to the load or stored directly by the energy storage device. Energy sustainability is based on TENGs and a power management circuit, which represents a key building block because it maximizes the power extracted from the TENGs and delivers it to the other building blocks. What is more, machine learning algorithms emerged as promising solutions to optimize the use and distribution of generated energy. ML helps reduce costs by streamlining processes and improving outcomes.

Embedded machine learning applications can make fast decisions or predictions closest to the original data source from flexible sensors. It is worth to mention that surface charge density that is affected by the surface roughness, polarity of the friction material, and contact area, is a key factor in measuring the output voltage, current, and power density.

The impact of comfort, wash durability, breathability, humidity, and temperature on fabric-based TENGs should be taken into account. Gradual peeling of the coated material with repeated washing also needs to be taken into consideration. Furthermore, 3D-structure based TENGs primarily designed for vertical motion are well suited for bioenergy harvesting, particularly in the context of human motion. In recent years, a large number of TENGs based on degradable materials have emerged and aim to provide green and eco-friendly energy. In this paper, the degradable materials used in TENG are classified into two categories: Animal-based degradable material, such as silk, and Plant based degradable material, such as cotton, cellulose, and alginate. The development of TENG based on degradable materials will promote next-generation green energy technologies. It is expected that this review will inspire further development of green, economical, and biocompatible energy harvesting systems incorporating natural-materials-based TENGs. The advances made in mechanical resistance, sustainability, and bio-compatibility, can eventuate in remarkable progress in the commercialization of TENG in the industry.

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## **DESIGN STRATEGIES AND METHODS FOR WORKWEAR IN THE TIRE INDUSTRY: A CASE STUDY APPROACH**

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### **ABSTRACT**

*This study investigates the design strategies and methodologies for creating workwear tailored to the specific demands of the tire manufacturing industry. In environments characterised by high temperatures, mechanical risks, and exposure to hazardous substances, it is crucial to design workwear that balances protection, comfort, and flexibility. The paper highlights key design principles such as ergonomics, material selection, safety features, and brand alignment. Using data derived from a multi-university design competition and industry reports, this study integrates practical case studies and survey data to demonstrate how creativity, functionality, and aesthetics can inform effective workwear design. The paper also includes an in-depth analysis of worker preferences, based on detailed surveys and interviews, providing valuable insights into the specific design requirements for workwear in tire manufacturing. A case study on a tire manufacturing company's workwear collection is used to illustrate the application of these principles, ensuring that worker needs are met while promoting corporate identity.*

**Key words:** workwear design, tire manufacturing, ergonomics, safety features, brand identity

### **INTRODUCTION**

Workwear design plays an essential role in ensuring the safety, comfort, and performance of workers across various industries. Within the automotive manufacturing sector, workwear is especially critical due to the high-risk environments in which workers operate. Employees in automotive factories are routinely exposed to hazards such as extreme heat, chemical exposure, mechanical risks, and repetitive tasks (Ayyappan et al., 2009). These conditions demand workwear that does not only protect the wearer from injury but also enhances their comfort, mobility, and overall job satisfaction (Bhise, 2012). The need for high-quality, functional, and durable workwear is thus fundamental to improving worker safety and productivity.

Automotive manufacturing processes are characterised by complex tasks involving heavy machinery, elevated temperatures, and extended hours of operation. Workers in departments such as welding, painting, and assembly face distinct challenges necessitating specialised workwear solutions. For instance, individuals working in welding zones must endure intense heat and sparks, whereas those in painting require protection against volatile chemicals and fumes. At the same time, assembly line workers often require garments that allow freedom of movement to facilitate repetitive manual tasks (Palupi et al., 2017). These divergent functional demands indicate that designing a “one-size-fits-all” uniform for such an environment is problematic (Kumar & Singh, 2021).

Despite these demands, the design of workwear in the automotive sector has often been driven primarily by industrial standards and cost-efficiency, with relatively less emphasis on ergonomics, comfort, and worker satisfaction. Many designs prioritise basic injury protection but overlook the

ergonomic needs of workers who perform physically strenuous tasks over long durations. Moreover, although safety features have traditionally dominated design criteria, comfort and freedom of movement are equally important to ensure continuous productivity. Research shows that workers wearing ill-fitting or uncomfortable uniforms experience increased fatigue and reduced productivity, which can compromise overall operational quality (Brisbine et al., 2022).

In addition to comfort and safety, aesthetic appeal and brand identity are increasingly recognised as important components of modern workwear design. Organisations striving to enhance employee morale and foster a sense of belonging are moving beyond purely functional workwear towards uniforms that reflect company branding, visual identity, and employee engagement (Nelson & Bowen, 2000). Studies indicate that employees who identify with their employer's brand and take pride in their appearance tend to report higher levels of job satisfaction and organisational loyalty (Surrett, 2021). Although such research is less abundant in the automotive manufacturing context, the trend is relevant given the sector's evolving workforce dynamics (Barnes & Newton, 2020).

Despite the growing acknowledgment of workwear's importance, there remains a notable gap in the literature regarding comprehensive, industry-specific investigations of workwear design for automotive manufacturing. Much of the existing research focuses on general industrial settings or investigates isolated dimensions such as textile performance or ergonomic assessment. Few studies have explored how comfort, functionality, brand alignment, and aesthetics interact within the automotive manufacturing context, particularly considering the diverse needs across production lines (Caseriu & Blaga, 2024). Therefore, a holistic approach integrating these dimensions remains under-explored.

This paper aims to bridge this gap by examining design strategies for workwear in the automotive manufacturing industry, focusing not only on safety and material performance, but also on ergonomics and worker satisfaction. By integrating both quantitative survey data and qualitative interview insights, the study provides a detailed analysis of workers' needs and preferences. Specifically, the research investigates how brand alignment, comfort, and freedom of movement can be integrated into workwear design to enhance worker productivity and safety, while concurrently contributing to company branding and employee morale. The paper also explores the implications of these findings for future workwear design in the automotive sector and provides practical recommendations for manufacturers seeking to improve their workwear systems.

## **THEORETICAL BACKGROUND AND DESIGN STRATEGIES**

Effective workwear design requires a multi-dimensional approach, incorporating not only protective features but also factors such as comfort, ergonomics, and alignment with company branding. The following sections outline the essential principles of workwear design, which include material selection, ergonomics, safety features, and aesthetic considerations.

### **Ergonomics**

Workwear must be designed to facilitate ease of movement and comfort while reducing strain on the worker's body. In the automotive manufacturing industry, workers are often required to perform repetitive tasks that demand both strength and flexibility. Therefore, workwear must be engineered to support movement, particularly in the shoulders, elbows, and knees (González et al., 2024). Studies have shown that ergonomically designed workwear can reduce fatigue and improve overall worker performance (Morris & Wilson, 2000).

### **Material Selection**

The choice of materials is crucial in ensuring that workwear performs well under the challenging conditions of automotive manufacturing. Fabrics need to be durable, comfortable, and resistant to wear, while also providing protection against heat, chemicals, and mechanical hazards. Materials such as flame-retardant cotton blends, chemical-resistant polymers, and moisture-wicking fibres are essential for automotive workwear (Watson et al., 2022). Additionally, the material must support breathability to ensure comfort during long shifts (Yoo & Barker, 2005).

### **Safety Features**

Safety is the foremost concern when designing workwear for hazardous environments such as automotive manufacturing. Workwear must be equipped with protective features such as flame-resistant fabrics, reinforced zones for high-risk areas (e.g., knees, elbows), and chemical-resistant coatings. High-visibility elements, such as reflective strips, are also essential to enhance safety in poorly lit or high-risk areas (Aly et al., 2014; Coca et al., 1995).

### **Alignment and Aesthetic Appeal**

While functional aspects of workwear are the primary concern, aesthetic considerations also play an important role in aligning workwear with the company's brand identity. A well-designed uniform can enhance employee morale and foster a sense of pride in the workplace. Research has shown that brand alignment in workwear can contribute to improved employee satisfaction and organisational loyalty (Surrett, 2021).

## **METHODOLOGY**

### **Questionnaire Design**

The survey included 25 closed-ended questions, addressing five key dimensions:

- Material Comfort (e.g., How comfortable do you find the workwear material during long shifts?)
- Freedom of Movement (e.g., Does the workwear allow for sufficient freedom of movement?)
- Protection and Safety Features (e.g., Does the workwear adequately protect against high temperatures and mechanical hazards?)
- Brand Recognition (e.g., Do you feel that the workwear reflects the company's brand?)
- Colour and Aesthetic Appeal (e.g., How satisfied are you with the appearance and colour of the workwear?)

Each question was rated on a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). The questionnaire was designed to gather insights not only into functional requirements but also into workers' subjective preferences and satisfaction levels.

### **Sample Selection**

This survey was conducted among 150 workers from various production lines in a large automotive manufacturing plant. The workforce included employees in assembly, welding, painting, and inspection departments. A total of 140 valid responses were collected, giving an effective response rate of 93.3%. The sample demographics are as follows:

- Male Workers: 100 (71%)
- Female Workers: 40 (29%)
- Average Work Experience: 3.5 years (range: 2–25 years)
- Average Shift Duration: 8.5 hours per day

## In-depth Interviews

Following the survey, 15 workers (5 from each department) were selected for in-depth semi-structured interviews. These interviews focused on exploring specific pain points in their current workwear, such as comfort issues, protection requirements, and their preferences for design and aesthetics. The qualitative data were coded and categorised into key themes for further analysis.

## Data Processing and Analysis

The survey data were analysed using SPSS 27.0 software. Descriptive statistics (means and standard deviations) were calculated for each survey item. Additionally, One-Way ANOVA was used to examine differences in workwear needs across departments (e.g., assembly, welding, painting). The interview data were transcribed and analysed using thematic coding to identify recurring patterns and insights.

## RESULTS AND DISCUSSION

### Survey Results

Table 1 summarises the mean scores and standard deviations for each of the five key dimensions measured in the questionnaire.

*Table 1: Descriptive Statistics of Key Dimensions in the Workwear Design Survey*

<b>Dimension</b>	<b>Mean Score (5-point scale)</b>	<b>Standard Deviation</b>	<b>Explanation</b>
Material Comfort	4.32	0.61	Workers rated the comfort of materials as high, reflecting a desire for breathable fabrics
Freedom of Movement	4.28	0.64	Flexibility of movement is essential, with workers needing freedom in areas like shoulders and knees
Safety and Protection	4.45	0.55	High ratings indicate that protection against heat and mechanical risks is a priority
Brand Recognition	3.58	0.92	Less emphasis on brand, but still important for company morale and identification
Colour & Aesthetic Appeal	3.71	0.81	A moderate level of satisfaction with the workwear's appearance and colour

### Data Analysis

The data analysis revealed several important trends and insights as follows.

- **Material Comfort:** The mean score of 4.32 for material comfort suggests that workers generally find the workwear comfortable, but there is still room for improvement, particularly in breathability. Workers in the welding department rated comfort lower (mean score 4.05), likely due to the intense heat exposure, whereas workers in assembly rated it higher (mean score 4.50), likely due to less strenuous physical demands.
- **Freedom of Movement:** The overall mean score of 4.28 indicates that most workers feel their workwear allows for adequate movement. However, specific feedback from the painting

department revealed that the arms and torso area of the workwear were considered restrictive, leading to a slightly lower score of 4.15. Workers in the assembly department rated movement freedom higher (4.50), as their tasks are more varied and require greater flexibility.

- **Safety and Protection:** The highest-rated dimension was Safety and Protection (4.45), reflecting the significant priority workers place on protective features. This is especially critical for those in high-risk areas such as welding, where the risk of burns and mechanical injury is high. The workers in the welding department rated safety features the highest (4.80), with specific requests for better flame-resistant materials and more reinforced padding around vulnerable areas.
- **Brand Recognition and Aesthetic Appeal:** This dimension received a lower rating (3.58), suggesting that workers do not view brand recognition and aesthetics as critical when compared to functionality and safety. However, several workers noted that the company's logo should be more prominently displayed to enhance corporate pride and identity. In particular, workers in assembly (mean score 3.85) seemed more aware of the visual appeal than those in welding (mean score 3.20), where protection was the primary concern.
- **Colour and Visibility:** A moderate score of 3.71 indicates that while visibility features such as reflective strips are valued, the overall appearance of the workwear is secondary to protection and comfort. Workers in the welding and painting departments rated visibility slightly higher, reflecting the importance of being clearly visible in hazardous, low-light environments.

### **One-Way ANOVA Results**

A One-Way ANOVA was conducted to examine differences in responses among assembly, welding, and painting departments. The results indicated that welding workers scored significantly higher on Safety and Protection ( $F = 5.24, p < 0.01$ ), reflecting their heightened awareness of safety risks due to the hazardous nature of their tasks. Assembly workers scored significantly higher on Freedom of Movement ( $F = 3.67, p < 0.05$ ), suggesting that their work requires greater mobility and thus emphasizes the need for flexibility in workwear design. No significant differences were found in Material Comfort or Colour and Aesthetic Appeal, indicating that these factors are commonly valued across all departments.

### **Interview Insights**

Interviews provided qualitative insights that complemented the survey findings. Welding workers emphasized the necessity for flame-resistant and heat-resistant fabrics, citing current uniforms as insufficient for protection against high temperatures. Assembly workers stressed the importance of breathability and flexibility, with requests for more stretchable materials around the torso and shoulders to enhance movement. Painting workers noted that their workwear often becomes heavy and restrictive after long use in humid conditions, suggesting that lighter fabrics could improve both comfort and performance.

### **DESIGN APPLICATION**

Based on the study, a design application for a tire manufacturing company was developed, illustrating how empirical findings can be translated into practical workwear solutions. The design proposal draws on data from a comprehensive survey conducted among workers in the automotive manufacturing sector. The objective was to create a workwear collection that satisfies workers' needs for safety, comfort, and brand identity while addressing the specific demands of various departments. The collection includes two major series: one for high-risk environments such as welding and chemical exposure, and another for general production tasks including assembly and quality control.

### Design Analysis and Survey Insights

The development of this workwear collection is closely aligned with the quantitative and qualitative insights obtained from the survey. Workers in high-risk areas, such as welding and vulcanisation, rated safety as their highest concern (mean score = 4.45). Consequently, the high-risk series integrates advanced protective materials, reinforced protective zones, and flame- and chemical-resistant fabrics to enhance occupational safety (Gupta, 2024; Watson, 2022). Meanwhile, employees in general production valued freedom of movement (mean score = 4.28) and overall comfort (mean score = 4.32), prompting the inclusion of elastic and breathable fabrics that reduce fatigue during extended shifts (Li et al., 2024; Bragança et al., 2015). Although aesthetic appeal was ranked lower, many workers expressed that having the company logo or color scheme on their workwear reinforced a sense of professional identity and unity. The integration of branding therefore supports morale and organizational cohesion (Smith et al., 2018).

### Visual Analysis of Designs



*Figure 1: Workwear Design 1*

This design incorporates reinforced padding and flame-resistant materials to protect workers in high-risk environments like welding. The workwear features reflective stripes to enhance visibility and safety, while the Tire company’s logo prominently displays the company’s identity. The dark blue and orange highlights design is both functional and modern, visually reinforcing safety and professionalism.



*Figure 2: Workwear Design 2*

Designed for comfort, this collection focuses on freedom of movement and breathability. The stretchable fabrics and ergonomic cuts ensure that workers can carry out repetitive tasks without discomfort. The Tire company's logo on the chest and back helps to promote the company's brand identity, while the design remains professional yet comfortable for daily use.

The tire workwear collection effectively addresses the diverse needs of workers across different departments in the tire manufacturing industry. The high-risk series prioritises safety and visibility, ensuring that workers in hazardous environments are adequately protected. The general production series focuses on comfort, freedom of movement, and brand alignment, ensuring that workers performing repetitive tasks have the comfort and support they need while feeling connected to the company's identity. These designs represent an integrated approach to workwear design that balances protection, comfort, and corporate branding. By utilising insights from the survey and applying ergonomic principles, these workwear designs enhance both the safety and morale of the tire company's employees.

## CONCLUSION

This study underscores the critical role of safety, comfort, and identity in the design of workwear for automotive manufacturing environments. The findings confirm that protective performance and ergonomic flexibility are the most valued attributes among workers, especially in high-risk or physically demanding roles. Although aesthetic and branding factors are secondary, they nonetheless contribute to workers' sense of belonging and professionalism. Future developments in industrial workwear should continue to integrate functional protection with ergonomic innovation and sustainable materials, ensuring that design responds not only to safety standards but also to the evolving expectations of industrial workers in the modern manufacturing sector.

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## THE RELATIONSHIP BETWEEN STITCH DENSITY AND SEAM STRENGTH IN COTTON FABRICS

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### ABSTRACT

*The aim of this study was to investigate the influence of three different weft yarn densities (10, 17, and 25 cm<sup>-1</sup>) as well as three different linear densities of weft yarns (20, 30, and 50 tex) on the seam strength of cotton fabrics. Seam strength testing was performed on specimens prepared in accordance with ISO 13935-1.*

*The samples were sewn in the warp direction using a selected stitch type designated as 1.01.01/301. During the testing of seam strength, F-ε curves were analyzed. It was observed that, for all samples, the force increased uniformly up to a certain point, after which a sudden decrease occurred, followed by a subsequent increase in force.*

*The region of the curve where the force begins to decrease was defined as seam slippage, indicating a significant deterioration of the seam structure at this stage. The results show that seam strength increases with increasing stitch density, weft yarn density, and linear density of the weft yarns.*

*The obtained findings are relevant for the garment manufacturing industry, as they enable more precise prediction and design of load levels that seams can withstand without compromising their quality.*

**Key words:** seam strength, cotton fabrics, weft density, yarn linear density, stitch density, seam slippage, seam quality.

### INTRODUCTION

Fast fashion production requires textile manufacturers to rapidly adjust fabric properties, most commonly by modifying weft yarn fineness and fabric density. Since fabric structure significantly influences garment performance, this study involved the production of samples with varying yarn fineness and fabric densities.

Seam quality depends on numerous factors, including material type, stitch type, stitch density, thread properties, needle type, and sewing speed. Previous studies indicate that the most severe damage occurs in trousers and skirts, particularly in regions subjected to high deformation and tensile loading.

The literature covers analyses of the influence of stitch density, stitch type, sewing direction, fabric density, thread properties, and other parameters on seam strength, yarn slippage, deformation, seam puckering, and durability of textile products. Due to the complexity of sewing conditions, there is no universal solution to the problem of seam damage.

Although breaking force is commonly used as the primary indicator of seam quality, this study demonstrates that functional seam degradation occurs prior to rupture, as a result of deformations that compromise structural integrity. Understanding these critical load limits enables a more precise definition of the maximum forces a seam can withstand before significant quality deterioration occurs.

### MATERIALS AND METHODS

This study investigated the effect of stitch density on seam strength in cotton fabrics. All fabric samples were produced under controlled industrial conditions on a single “Vamatex” loom equipped

with a rapier weft insertion system and an electronic yarn control system. To eliminate the influence of machine variability, all samples were woven on the same loom with a nominal width of 210 cm.

A 100% cotton plain weave fabric was used, with a constant warp configuration (40 tex; 24 ends/cm). Weft parameters were varied in terms of yarn density (10, 17, and 25 ends/cm) and yarn linear density (20, 30, and 50 tex). Yarn linear density and fabric mass per unit area were determined according to relevant SRPS ISO, SRPS F.S2.511, and SRPS EN 12127:2014 standards.

For seam strength testing, specimens were prepared in accordance with ISO 13935-1. Samples measuring 350 × 700 mm were cut in the weft direction and folded so that the longer side was aligned with the fold. They were then sewn in the warp direction using stitch type 1.01.01/301 according to ISO 4916 on a Juki DDL-5550 universal sewing machine.

Sewing parameters were kept constant: 3,000 stitches/min, needle size Nm 90, presser foot pressure 2.8 N, and thread tension 0.50 N. Stitch density was varied in five levels, resulting in 3, 4, 5, 6, and 7 stitches/cm.

All seams were produced using the same 100% polyester sewing thread with a linear density of 47.7 tex, tensile strength of 23.37 N, and breaking elongation of 19.17%.

Seam strength testing was performed using a Tenso Lab 3 tensile tester (Series 2512A, Mesdan S.p.A., Italy), which provided precise numerical results and force–elongation (F–ε) curves. This enabled detailed analysis of the relationship between applied force and fabric elongation under controlled conditions.

Sample marking	Weave structure	Linear density $T_t$ (tex)		Yarn type		Density		Surface mass $m$ (g·m <sup>-2</sup> )
		for warp	for weft	for warp	for weft	warp $d_{wa}$ (cm <sup>-1</sup> )	weft $d_{we}$ (cm <sup>-1</sup> )	
		A	Plain 1/1	40	50	100 Co	100 Co	
B	Plain 1/1	40	30	100 Co	100 Co	24	25	190,32
C	Plain 1/1	40	20	100 Co	100 Co	24	25	153,40
D	Plain 1/1	40	50	100 Co	100 Co	24	17	175,77
E	Plain 1/1	40	30	100 Co	100 Co	24	17	154,45
F	Plain 1/1	40	20	100 Co	100 Co	24	17	132,30
G	Plain 1/1	40	50	100 Co	100 Co	24	10	153,40
H	Plain 1/1	40	30	100 Co	100 Co	24	10	136,52
I	Plain 1/1	40	20	100 Co	100 Co	24	10	121,75

*Table 1. Different fabric samples sewn in the weft direction with the sewing seam type 1.01.01/301*

## RESULTS AND DISCUSSION

The development of modular textile systems typically begins with the adaptation of simple geometric forms derived from regular tessellations of the plane. Basic polygonal units serve as the foundation for modular construction, where each element is designed to function as both an individual component and part of a larger interconnected system.

Connection mechanisms are integrated directly into the geometry of the module, enabling controlled interlocking between adjacent units. Through repeated assembly, simple geometric forms can generate more complex configurations, such as multi-unit structures with increased spatial depth and surface variation.

The interaction between modules may also produce layered effects and secondary structural patterns, enhancing both the visual and tactile qualities of the textile surface. In this way, modular systems demonstrate how geometric simplicity can be transformed into complex and adaptable material architectures through rule-based assembly and spatial organization.

Figure 1. shows the correlation between the force at the yield point of the seam and the total breaking force of the seam for samples with thread density per weft of 25 cm<sup>-1</sup>, 17 cm<sup>-1</sup> and 10 cm<sup>-1</sup>.

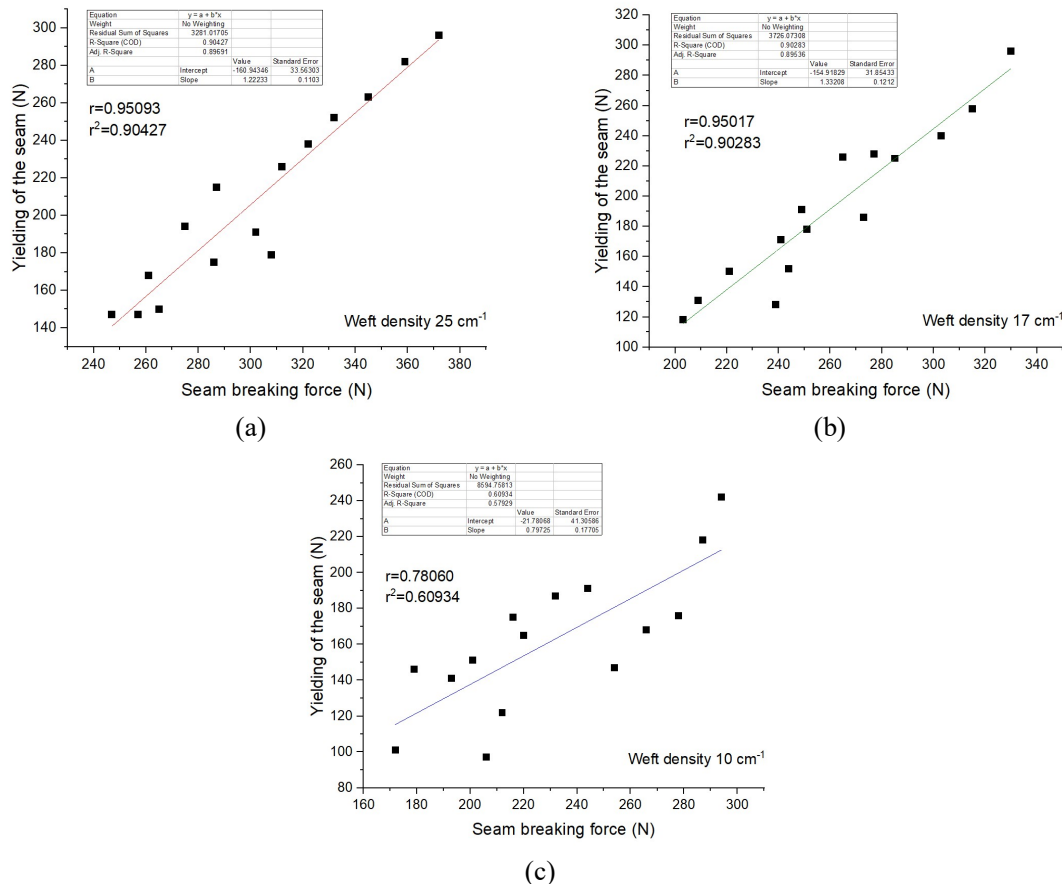


Figure 1: Representation of the correlation between yield strength and seam breaking force in fabrics with weft thread density of 25 cm<sup>-1</sup> (a), 17 cm<sup>-1</sup> (b) and 10 cm<sup>-1</sup> (c)

This study clarifies the influence of stitch density on the seam strength of cotton fabrics. Analysis of F-ε curves showed that force increases uniformly up to a certain point, followed by a sudden drop and a subsequent increase until final seam rupture. The region where the force decreases was defined as seam yielding, indicating a significant loss of structural integrity. This point represents the critical load level at which functional degradation of the seam begins, prior to complete failure.

The results indicate that weft yarn linear density and fabric density have a pronounced effect on seam behavior under load. Higher values of these parameters increase inter-yarn friction and structural compactness, leading to improved resistance against yarn slippage and higher yielding and breaking forces. Conversely, lower fabric density increases inter-yarn spacing, facilitating yarn mobility and reducing mechanical stability.

It was further confirmed that increasing stitch density significantly enhances seam strength. Denser stitching distributes applied loads more evenly along the seam line, reduces stress concentration, and limits yarn displacement within the seam structure. As a result, seam resistance increases both at the yielding stage and at ultimate failure.

In a broader context, the findings demonstrate that seam performance cannot be evaluated solely based on breaking force, but must also consider pre-failure behavior. The yielding phase is a crucial indicator of functional degradation in real garment use, as visible and structural damage may occur before complete seam rupture, affecting both aesthetic and functional quality.

Therefore, stitch density, fabric density, and yarn linear density should be considered as interdependent parameters in textile engineering. Understanding their combined influence enables more accurate seam design capable of withstanding real service loads while maintaining structural stability and garment quality.

## CONCLUSION

During the study, it was observed that seam strength testing can result in different types of failure, including fabric rupture, thread breakage, and yarn pull-out. Only specimens in which failure occurred directly at the seam were considered relevant, while all other cases were excluded from the analysis.

Video analysis of the testing process showed that force and elongation initially increase uniformly, followed by a sudden drop in force and a subsequent increase until final seam rupture. This point of abrupt force reduction was defined as seam yielding, indicating visible structural damage, even though the testing device continues until complete failure. This behavior demonstrates that seam degradation occurs well before final rupture.

The results confirm that stitch density has a significant influence on both seam yielding force and breaking force. Increasing stitch density improves seam structural stability, resulting in higher force values throughout all loading stages. Even after yielding occurs, higher stitch density ensures greater residual strength until final failure.

It was also confirmed that weft yarn density has a strong effect on seam mechanical behavior. Samples with the highest density (25 ends/cm) exhibited the highest yielding and breaking forces, followed by 17 ends/cm, while the lowest values were recorded for 10 ends/cm. Minor deviations were observed only at certain stitch densities (e.g., 3 and 5 stitches/cm), indicating local variations in stress distribution.

Furthermore, yarn linear density significantly influences the results. Samples with coarser yarns (50 tex) showed the highest force values, followed by 30 tex, while the lowest values were obtained for 20 tex. Average yielding forces decreased by approximately 20–38% when finer yarns were used, confirming the importance of yarn fineness in seam stability.

The findings indicate that coarser yarns and higher fabric density effectively restrict yarn slippage within the seam area. In fabrics with higher density (25 ends/cm), inter-yarn spacing is reduced, increasing friction and structural stability. This enhances resistance to deformation and improves the correlation between analyzed parameters. As fabric density decreases, inter-yarn spacing increases, facilitating yarn mobility under load and reducing seam stability and mechanical performance.

In a broader context, the results clearly show that seam quality cannot be evaluated solely based on breaking force, but must also include the yielding phase, which represents the onset of structural degradation. This phase is particularly important, as deformation in real garment use can compromise both aesthetic and functional properties before complete seam failure occurs.

In conclusion, seam strength is the result of a complex interaction between stitch density, fabric density, and yarn linear density. Increasing these parameters significantly improves mechanical resistance and seam stability. Understanding their combined influence enables more precise textile product design and optimization of sewing conditions, ultimately improving garment durability and quality in real use.

In this study, the influence of stitch density on the seam strength of cotton fabrics was analyzed by monitoring the F- $\epsilon$  curve. For all samples, a continuous increase in force was observed up to a point of sudden drop, followed by a subsequent increase until final seam rupture. The first force drop was defined as seam yielding, indicating significant structural degradation and representing the critical load level that a seam can withstand without compromising garment quality.

The results show that both seam yielding force and breaking force depend on the linear density of weft yarns. The highest values were obtained for samples with 50 tex yarns, followed by 30 tex, while the lowest values were recorded for 20 tex. The reduction in average yielding force ranges from approximately 20% to nearly 40% when finer yarns are used. This trend is consistent across all sample groups (A-I), confirming that coarser yarns provide greater resistance to seam deformation.

It was concluded that seam strength increases with increasing stitch density, weft yarn density, and yarn linear density. These parameters represent key factors in garment construction optimization, as they enable more accurate production planning and definition of maximum loads that seams can withstand without compromising the functional and aesthetic properties of the product.

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## **DIGITAL FASHION DESIGN: APPLICATION OF CLO 3D SOFTWARE FOR GARMENT PATTERN DEVELOPMENT AND SIMULATION OF A WOMEN'S OUTFIT**

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### **ABSTRACT**

Digital fashion has led to countless opportunities and conveniences in the development of contemporary fashion design. Due to their advantages, various CAD software tools intended for the digitalization and simulation of clothing have become the most frequently used tools in the creative process of prototype development. One such example and a leading software is CLO 3D, whose capabilities in the process of pattern development and clothing simulation will be presented in this paper. From the initial idea to the virtual prototype, CLO 3D enables a realistic visualization of clothing in a virtual space, simulating all its features and capabilities. Through a practical example combined with 2D design, a 3D model of a women's outfit was developed, which allowed for its realistic rendering. Based on the achieved results, this paper examines and confirms the capabilities of CLO 3D software as an efficient tool in fashion design, emphasizing the benefits of digitalization and virtual garment simulation as a reflection of a contemporary and advanced fashion system.

**Key words:** digital fashion design, 3D simulation, CLO 3D, CAD software, digital prototype

### **INTRODUCTION**

The development and use of digital tools have led to new ways of thinking about innovative approaches to fashion design and considerations, as well as the transformation of design practices (Choi, 2022), which has contributed to new creative opportunities for the expression of fashion and textile designers. The increasing application of digital technologies in the development of fashion design has had a positive impact on everyday sustainability issues in the fashion industry. In the development of fashion design, digital technologies and their capabilities have become one of the indispensable tools for simulating virtual clothing prototypes before the actual production process (Petрак, 2023). Digital design and simulation software have continuously evolved in line with the development of technology and 3D graphics. The initial media used in the design development process, dating back to the mid-1990s, such as Photoshop, Illustrator, and AfterEffects, began to be utilized in various creative industries, and continued to be used and developed to this day. A new digital aesthetic started with the use of software for 2D and 3D visualization of clothing, which today is much more complex and includes the rendering of all garment performances. Some of the most renowned and leading 3D software for virtual garment simulation include Browzwear's V-Stitcher, Optitex's 3D Suite, Lectra Modaris 3D, Human Solutions' Vidya, Techno A's i-Designer, CLO Virtual Fashion's CLO3D, Marvelous Designer, and Physan's DC Suite (Choi, 2022). For a long time, traditional 2D design tools like Adobe Illustrator and Corel Draw, in combination with CAD systems for garment development such as Gerber, Lectra, and Assyst, enabled pattern preparation in 2D form, where the focus was on 2D drawing and pattern modification. However, a significant moment in the mass adoption of 3D tools in fashion design also meant a reduced need for physical samples, achieving an innovative leap in the design process and opening new possibilities for sustainable development and clothing production (Eren, 2025). With the development of computer graphics, the accuracy and precision in 3D garment model development have significantly improved over time (Jankoska, 2020). Today, CLO 3D, Optitex, and Marvelous Designer are recognized as the

most well-known and frequently used software in the field of the fashion industry. Thanks to their advantages, they allow designers to create 2D patterns, perform 3D virtual fitting, and simulate fabric using avatars during the design process, which reduces the need for physical samples, contributes to waste reduction, and optimizes production (Eren, 2025). Ultimately, all the listed software allows users a virtual review of the prototype, after which conventional production can proceed. The primary goal is the integration of 3D garment models into the production system (Periyasamy & Periyasami, 2023). Research on the topic of fashion digitalization between the period of 2015 and 2025 has revealed the significant application of such software (Eren, 2025), owing to the animation capacity, visualization aesthetic, and realism they offer.

Specifically, CLO 3D has highly developed capabilities when it comes to advanced simulation and rendering options, which enables the virtual presentation of entire fashion collections in the form of fashion shows and the simulation of avatars in various interactive environments (Eren, 2025). As such, CLO 3D was used for the purposes of this paper as software that, thanks to its properties, allows the designer complete visualization, experimentation in a virtual space and avatar interaction, thereby achieving a realistic effect of the overall design. Throughout the entire process, from 2D pattern creation to the interactive process, it was very quick and efficient to spot potential errors, simulate the pattern in combination with the fabric, and observe the fabric's behavior during interaction, which would further eliminate potential design problems in the physical form.

### **Overview of CAD (Computer Aided Design) Software in the Fashion Industry**

CAD (Computer Aided Design) technology for apparel is the use of computer technology to assist in the design of garment products (Eren, 2025). CAD systems were originally developed in the 1960s for other industries, specifically due to their precision, and their application in the textile industry began to develop in the 1970s. Currently, their application is at a global level. CAD systems are specialized as contemporary technology for technical-design solutions in the design and production process. Additionally, besides enabling two-dimensional solutions, they also allow for an automated process of product visualization in the form of a prototype. Some of the most important characteristics and capabilities are cooperativeness and productivity alongside very clear communication between the software and the user, that is, the designer. They are intended for fast and efficient changes, and for improving the overall process. In addition to creating sketches and technical solutions, the creation of 3D models in the mentioned software allows for interaction through materials, colors, prints, and their visualization (Khan et al., 2024). The development of CAD systems also led to the development of 3D technology, which enabled the optimization of processes within the fashion industry, created a need for creative solutions, and resulted in textile waste and pollution becoming an important topic for the fashion and textile sector (Eriksson & Kabakibi, 2023). Historically, the evolution of fashion has intertwined with the development of industry and technology. The development of digitalization also led to the simplification of the entire production process, including easier communication between the designer and the production department. This was evident through the very fast generation of sketches into pattern creation, and virtual fitting, which improved the efficiency of garment development.

### **CLO 3D as Software in Digital Fashion Design**

Specifically, CLO 3D is a software for digital garment development and simulation that originated in South Korea and has become one of the leading software applications utilized in collections by famous fashion brands, online stores, education, and researches, as well as for the purpose of visualizing textiles in interiors. Famous brands such as Adidas, Patagonia, Amazon, Lindex, Li&Fung, and Helmut Lang have already applied this software in their fashion collection development process, thereby achieving efficient prototype development with minimal waste (Guo & Hou, 2022; McQuillan, 2020). CLO 3D enables its users to design, develop, and simulate apparel products, and the process itself allows for garment pattern creation, digital coloring, and the simulation of patterns and fabric in a realistic visualization (Eren, 2025). Everything from the

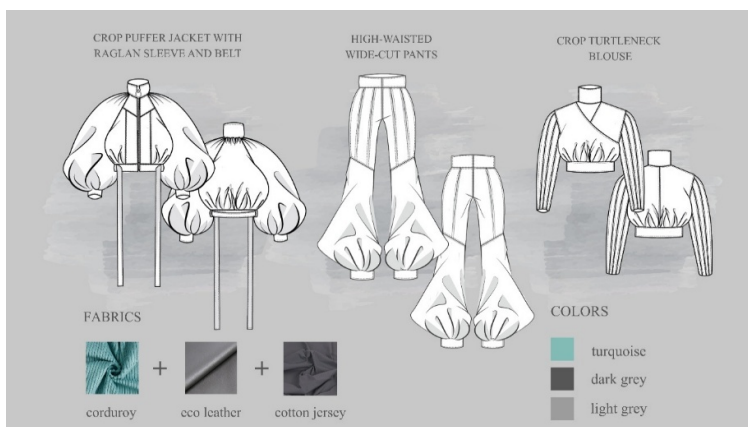
conceptualization of the idea to the final prototype of clothing or fashion accessories, thanks to all the available tools it contains (Khan et al., 2024), allows designers complete creative freedom and different forms of expression. Accordingly, it represents one of the leading software when it comes to simplifying the design process while advocating for its sustainable approach. Unlike traditional garment design, every software for three-dimensional clothing shaping offers its own benefits such as dynamic and interactive design, as well as modification and transformability during the simulation process. The integration of software like CLO 3D into the design development process represents one of the key aspects of apparel production, which is linked to an improved approach in analyzing garment fit to the body and increases the efficiency of anthropometric measurements.

## METHODS

The methods used in the experimental part of this paper are the development of 2D garment patterns based on the initial design idea in the form of a sketch, that is, the transformation of the technical drawing of the entire women's outfit into a two-dimensional form. Next, the following step was the transformation of the two-dimensional flat garment patterns into a three-dimensional form with the help of an avatar in a virtual space. Thanks to all the tools that CLO 3D software offers, this creative process allowed for the complete visualization of the initial idea, including the form and patterns, the structure and texture of the fabric, and their mutual relationship in an interactive space, which would translate into an improved prototyping process and overall garment production in further physical prototype development. The method of work was specifically used for visual prototyping, where the goal was not the production of a physical prototype, but to explore the capabilities of the avatar in a virtual environment based on the initial garment design, which could potentially result in and improve the physical production of the prototype.

### Technical drawings as the basic starting point of the digitalization process

The first form in the emergence of fashion design is the initial sketch, which is subsequently reshaped into a technical drawing. During the process, the technical drawing can be adjusted according to a specific pattern so that it can be implemented into a physical form. The sketch is based on the initial idea, while the technical drawing represents communication between the design department and the production capabilities. It is very important to be expert with basic patterns, which can then be modified to fit the initial design. For this paper, the initial idea was inspired by urban street wear, combining fabrics such as eco-leather, corduroy and jersey in grey and turquoise, in order to contribute to an urban and modern style. The technical drawings of the complete outfit consist of a jacket, trousers, and a blouse, which were adapted through patterns, colors, and textile materials, shown in Figure 1. The technical drawings were drafted in Adobe Illustrator software, as a software that enables accurate and clearly defined vector drawing of two-dimensional garment shapes.

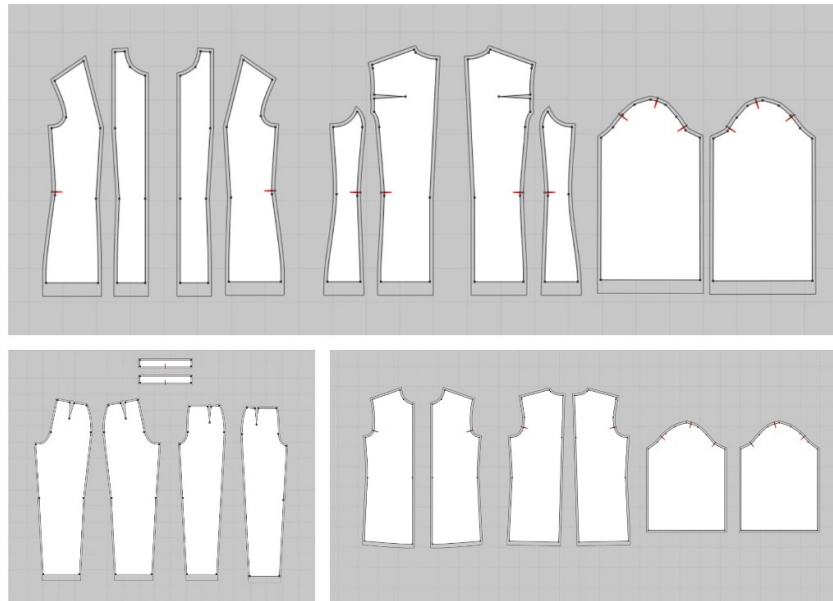


*Figure 1: Technical drawings and visualization of the women's outfit as the initial idea*

The entire idea for the outfit is connected through material and color, and the exact look of the conceived idea was achieved through the help of various tools in the CLO 3D software. By mastering the tools, the desired design was achieved through an understanding of patterns and form, and by applying tools for additional improvements in the design's appearance, such as special effects like clearer definition of the structure and texture of the fabrics.

### **Development of 2D garment patterns**

The development of a 3D design prototype begins with the creation of a 2D pattern, and the result of this is the generation of the final 3D form (Jankoska, 2020). Activity in the 2D window, shown in Figure 2, automatically sends information to the 3D window, which will later serve as the basis for forming the prototype. The sketch or technical drawing previously represented the initial step in the process of constructing and reshaping garment patterns. Drawing-based design methods provide a promising workflow in the overall process. For the precise creation of patterns, prior knowledge of garment construction is necessary, so that garments are adequate and adapted to the initial sketch, or technical drawing. The transformation of the idea itself into a pattern means understanding the design and mastering fundamental technical skills. Garments are constructed and customized according to valid clothing standards, size charts, and based on body shape. Specifically, for the experimental part of this paper, a standard size 36 was used, suitable for an athletic body type of a female. The key aspect is accurate body measurement and size definition, which enabled a harmonious and continuous process. The 2D window of the CLO 3D software offers the possibility of creating a flat pattern construction with all necessary tools, which resembles the traditional physical approach to garment pattern making. In this process, it was necessary to construct the foundational patterns of all the mentioned garments in accordance with the pattern models and body measurements, and then proceed to the process of reshaping and adapting them to the drawing.



*Figure 2: Two-dimensional shaping of the foundational garment construction in the 2D window*

During pattern reshaping process, shown in Figure 3, the efficiency in pattern transformation became evident. All potential mistakes, regarding measurement differences or, specifically, mistakes on the

pattern, could be quickly eliminated. Furthermore, on the precisely reshaped garment patterns, an additional possibility was the addition of and experimentation with fabric. By adding clearly defined fabrics, their colors, and textures, it already provided insight into how the two-dimensional garment shape can predict the final appearance of the prototype in the 3D window in a three-dimensional form.

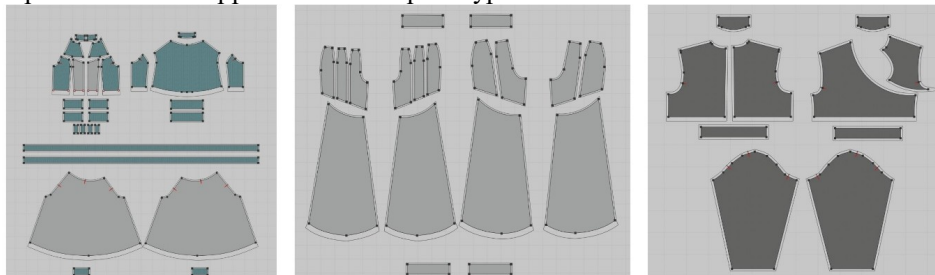


Figure 3: Two-dimensional view of garment patterns for the women's jacket, trousers, and blouse

### Transformation of 2D patterns into 3D form

3D software systems for virtual simulation are based on the method of starting with two-dimensional garment patterns to generate virtual sewing and three-dimensional shaping. Such a method encompasses several technologies, such as garment reshaping, virtual sewing, and collision detection technology. The conventional thinking of designers in the design development process can be cited as an advantage of this method (Jankoska, 2020). CLO 3D is one of the leading software in the transformation of two-dimensional shapes through 3D graphics. It also stands out among the most advanced digitalization software when it comes to rendering. Rendering actually represents the creation of a 3D model based on accurate two-dimensional data, which improves practical use and experimentation with different fabrics or colors (Khan et al., 2024), shown in Figure 4. After the garment parts were clearly created, the pattern lines in the two-dimensional form actually gained their shape in the three-dimensional form as assembly lines, representing sewing lines of the pattern pieces



Figure 4: 3D visualization of the women's outfit and simulation on the avatar

## CONCLUSION

In general, the digitalization of fashion and all the possibilities that software designed for it brings with it, has brought revolutionary changes to fashion and is constantly progressing. The process of designing and overall garment development has been significantly facilitated, thereby considerably improving efficiency and productivity in the fashion industry. This paper confirms just some of the possibilities that fashion digitalization brings, serving as an aid for fashion designers in the creative process of creation. The development of digitalized garment patterns, right up to their prototyping, represents an important aspect for designers because it enables them a better understanding of the design and how to reshape their own idea through a simulated display, which can serve as the basis for the physical form of the design. Time saving, reduction in material consumption, and the sustainability of the production process are increasingly important issues that can be the subject of future research on the topic of fashion digitalization, and its benefits are always a relevant topic for many researchers. Fashion digitalization is constantly progressing, evidenced by its possibility of combination with Augmented Reality (AR) and Virtual Reality (VR), which today redefines the way fashion designer brands can communicate with their consumers, that is, customers. Specifically, digital fashion brings several key advantages, such as greater possibilities for fashion designers, faster market arrival of their collections, and process sustainability compared to traditional garment production. In addition, it enables the creation of creative communities, which are increasingly represented today in online form through platforms that facilitate shared creativity and collaboration.

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## THE CURRENT SITUATION AND DEVELOPMENT NEEDS OF XINJIANG'S TEXTILE INDUSTRY

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### ABSTRACT

*Starting with partial review of Xinjiang's cotton plantation, this paper explains current situation of Xinjiang's textile supply chain which includes Xinjiang cotton shares in whole China cotton production area, and its geographic distribution of main textile spinning, weaving, knitting and clothing firms in Xinjiang region, with the information about China's government supporting policies. Second, this paper points out the main market directions of Xinjiang textile industry goods and explains that this region's textile and clothing industries have been faced unreasonable geopolitical suppression from U.S with so called "forced labor" issue in its UFLPA and points out some refuting points to this purely political suppression. Third, this paper collects a few analysis about the needs of Xinjiang textile and clothing industries' further development.*

**Key words:** Xinjiang cotton, Textile industry, Clothing industry, Supporting policies, Geopolitical suppression related with UFLPA, Development needs.

### 1. Review Development Process of Xinjiang's Textile Industry

The Xinjiang Uygur Autonomous Region (referred to as Xinjiang) has transformed from being China's primary cotton base into a comprehensive textile manufacturing hub. This growth is driven by national strategic priorities, abundant resources, and significant policy support.

#### 1.1 Strong Raw Material Foundation:

Traditionally China has greatly depended on cotton to solve people's basic clothing needs, but as China had large quantity of population (in 1950s, 22% of world total) while there were only about 9 percents of world cultivated land resource, growing cotton simultaneously to mean reducing the arable land used for growing food, so China has been facing challenge to balance cotton and grain plantation issue since earlier 1950s.

After new China set up, Xinjiang first tested cotton cultivation in Xiaoguai Reclamation Area in the Manas River Basin, north part of Xinjiang in 1950, people knew that there is good development prospects in this vast region. In order to improve cotton's fiber quality, Chinese scientists continuous test long-staple cotton plantation technology and seeds improvement test based on Russia offered original long-staple cotton seeds.

Gradually Xinjiang has increased the planting area and yield of cotton, from a production share of 1.1% of the national total in 1951, to a share of 92.2% in 2024, the miracle of Xinjiang cotton has thus come about! From China's cotton production statistics report of 2024, this paper put some data into following table 1.

**Table 1: Some main cotton production statistics of China's provincial level in 2024**

Region	Cotton plantation (1,000 hectare)	kilograms per hectare	Total output (thousand tons)
Nationwide total	2838.3	2171.6	616.4
Shandong	99.8	1273.9	12.7
Hubei	98.4	1211.8	9.3
Hunan	60.7	946.0	8.4
Hebei	57.9	1227.0	7.1
Gansu	22.2	2115.8	4.7
Xinjiang	2447.9	2322.8	568.6

Data source: Announcement by the National Bureau of Statistics of China on the Cotton Production in 2024

From Table 1: it is easily to know that Xinjiang's cotton plantation is 86.25% of all China's total, also Xinjiang's cotton production yield is far above other China's main cotton region, the output kilograms per hectare of Xinjiang cotton yield (2322.8 kg in 2024) is about 2 times of all four main provinces' mean (Shandong, Hubei, Hunan and Hebei's average cotton yield is 1164.7 kg / hectare) except Gansu province which is quite similar in geographic aspects of Xinjiang. Thus, there is no doubt that Xinjiang is the largest cotton-producing area in China and is truly the "cotton warehouse" of China. Meanwhile the quality of Xinjiang cotton is quite good for textile processing, long-staple cotton accounts for a large proportion.

By the way, China's textile industry also paid more attention to the diversification of textile materials in Xinjiang region, beyond cotton, the region is developing a chemical fiber sector, using local coal and petroleum resources to produce man-made fibers like viscose, reducing reliance on pure cotton.

### **1.2 Established and Growing Industrial Chain**

In recent years, the Xinjiang textile industry has developed very fast, and the supply chain from cotton cultivation to textile production to finished clothing has become increasingly mature. The capacity of spinning yarn has continually increased, as of the end of 2023, Xinjiang has established a yarn production capacity of approximately 20 million spinning spindles. Xinjiang now encompasses a more complete chain, including textile industry's upstream which includes cotton farming, ginning and chemical fiber production, midstream which includes spinning as major strength, weaving and knitting, as well as downstream which includes garment, home textiles and industrial textiles production that this downstream segment is the current focus for expansion.

So in this case, Xinjiang has got very good progress for textile and clothing industry development, which is an extremely core part of China's textile industry, and is ready to cooperate with domestic and international partners.

### **1.3 Significant Policy Support as an Experience in Economic Development**

Due to the policies adopted by the central government of China, which are governing Xinjiang in accordance with the law, maintaining unity and stability in Xinjiang, enriching the culture of Xinjiang, promoting prosperity and development in Xinjiang, and building Xinjiang over the long term, Xinjiang has received substantial financial support from the central government and the human resources and assistance projects from various provinces every year. As a result, various industries in Xinjiang, including the textile industry, have achieved rapid development.

As a newly document of "Xinjiang Textile and Garment Industry Development Nine New Measures" (2025) claimed, Xinjiang government intended to provide various subsidies, including investment subsidies, which includes financial subsidies, working capital loan interest subsidies, fixed-asset investment subsidies, and sales subsidies for downstream products. Also some local county government even provides employment incentives to give rewards for enterprises that create stable employment, particularly for the local population. Textile firms in those counties can also get electricity rate discount water supply preferential price to help those firms to reduce operation costs.

With such supporting policies, every year central government put great funding via transfer payment in order to balance regional development gaps (China's eastern parts developed more fast and western parts developed less fast), which has been proven to be a very effective policy for developing the economy. Meanwhile under such policies, Xinjiang has achieved comprehensive poverty alleviation. The people including the Uyghurs have gained more job opportunities (textile and clothing industry is one of main suppliers). Therefore, the people's lives in Xinjiang are getting better year by year. Thus, the claim that local Xinjiang people (Uyghurs) have been forced for labor is truly political slander from some foreign politicians, which will be explained late in this paper.

### **1.4 Formation of Textile Industrial Clusters:**

According to the initial survey, the distribution of the textile industry in Xinjiang (both northern and southern parts) is roughly as follows.

Southern Xinjiang: Areas like Aksu, Kashgar, and Hotan are key for labor-intensive industries such as spinning and clothing firms, which have been heavily supported by poverty-alleviation initiatives. For example, in Aksu city there are three key textile firms, Huafu Fashion Co., Ltd., Zhejiang Juying Group Xinjiang Co., Ltd. and

Xinjiang Yiling Textile Co., Ltd. They are all mainly located in Aksu industry center, which local government purposely planned and made big investment for electricity, water supply and other infrastructure construction.

Northern Xinjiang: Centers like Shihezi, Korla and Karamay have more advanced spinning and chemical fiber production. For example, Xinjiang Zhongtai (Group) Co., Ltd is one of the largest firms in Xinjiang's textile and chemical fiber sector and it has production capacity of cotton spinning over 3 million spindles, over 20,000 looms for grey fabrics and significant dyeing & printing ability as well as capacity to produce tens of millions of garments per year. Other large textile firms are like Luthai Textile Co., Ltd, which has its production base in in Shihezi city, Huafu Fashion Co., Ltd, which is mainly located both in Kuitun (Northern Xinjiang) and Aksu (Southern Xinjiang).

**1.5 Social and Economic Impact:**

The Xinjiang textile industry is a critical tool for employment generation, aiming to provide stable jobs for hundreds of thousands of people from rural areas, contributing to social stability and poverty alleviation. With the tool of Chinese AI Platform DeepSeek, this paper has copied some employment information related with Xinjiang textile industry in table 2 as follows:

**Table 2 Some information about Xinjiang’s textile employment**

Textile Firm or Area	Data related with employment	Remark
Aksu Prefecture	New employment 17,806	Within 2016, most related with Textile
Kashgar Prefecture	2500	the first quarter of 2025
Xinjiang Tangjing Textile Co.	Direct employment 1200, with 3000 people as part time family workers	Till April of 2025
Tushuk City	4795 new employment	From January to July of 2025
Bachu County Recruitment	3700	Related with textile, July 2025

Source: DeepSeek based on 10 original web reports in November 2025

From above table, it is easily to know that Xinjiang’s textile industry has greatly provided big employment opportunities to local people. Also this paper checked "Development Plan for the Textile and Apparel Industry in Xinjiang (2018 - 2023)", which has listed the target of one million of employment in the period of 2018-2023. According to this paper author’s visiting in Southern Xinjiang region (Wensu, Shaya and Alaer, all are local county), there are existing at least 3 million spindles of spinning capacity in each county with several large scale textile firms, some of which have been successfully developed for about 10 years. Thus Southern Xinjiang textile industry has greatly contributed for local employment and economic development.

**2. The Market Analysis of Xinjiang Textile Industry and its Geopolitical Challenge**

Regarding the main sales direction of Xinjiang textiles, it can be easily classified as two markets, domestic market as key direction, and near by Asian countries’ market as main international markets. Meanwhile Xinjiang has been facing geopolitical challenge from some western countries since 2020.

**2.1 Domestic market**

Domestic market is the most core and stable sales for Xinjiang's textile products, the flow of which mainly consists of two parts. Each year, a large amount of high-quality Xinjiang cotton yarn and raw fabrics are transported to provinces, such as Henan, Jiangsu, Zhejiang, Shandong and Guangdong, which have owned more advanced textile industries as well as sophisticated garment industry supply chain in the mainland for further processing and to produce high quality garments and home textiles.

Final products, with the guider of Xinjiang regional economic development strategy of "the extension, supplementation and strengthening of supply chain", Xinjiang textile and clothing enterprises are also continuously expanding the production and sales of final products, which are mainly home textiles and high quality cotton fabrics. The main distribution channels are large scale wholesale markets such as Guangzhou Baima (White Horse) market and Yiwu Market (the largest commodity market in the world located near Hangzhou, capital city of Zhejiang Province), e-commerce platforms, as well as through cooperation with mainland brands, thus, the products are sold throughout the country.

## **2.2 International Markets**

Geographically, Xinjiang is bordered by eight countries including four Central Asian countries, Russia, Mongolia, India and Pakistan. There are currently two railway ports and multiple land auto ports. So, Xinjiang's textiles (especially clothing and fabrics) are exported in large quantities to Central Asian countries such as Kazakhstan, Kyrgyzstan, and Uzbekistan, and some of them are re-exported to Russia and other Eastern European countries. This is a unique advantage of Xinjiang's foreign trade.

Meanwhile, Xinjiang has also exported cotton yarn and fabrics to countries in East Asia and South Asia, such as Vietnam and Bangladesh and so on.

## **2.3 Geopolitical Challenge Related with so Called “Forced Labor” Issue**

Traditionally, the United States and EU market segments accounted for a large share of Xinjiang textile and clothing products, but in recent years (mainly 2020 to now) it has been significantly affected and hindered due to the so-called "forced labor" imposed by the United States on products from Xinjiang with their domestic law of UFLPA (Uyghur Forced Labor Prevention Act). Here, based on some literature research with the AI tool DeepSeek, this paper would like to take a look at how the domestic laws of the United States, which slander China, has evolved to an impact on Xinjiang.

First, on March 12, 2020, the New York Times published an article stating that the FLA ( "Fair Labor Association" of the United States.) has asked its members to investigate the issue of "forced labor" in Xinjiang, and brands such as Nike and Patagonia responded, which was based on those western entity and media's misunderstanding of Chinese government's counter-terrorism activities in the period of 1990-2016, which is mainly represented by the "East Turkestan" forces.

Second, on September 15, 2020, the U.S. Customs and Border Protection Agency prohibited the import of products from 5 Chinese companies and 1 manufacturing plant on the grounds of "forced labor", which is derived from their political correctness.

Third, On December 2, 2020, the United States Department of Homeland Security announced the imposition of a pre-emptive ban on cotton and cotton products produced by the Xinjiang Production and Construction Corps and its affiliated entities.

Fourth, on December 2020, BCI (Better Cotton Initiative), a non-profitable organization based in Switzerland once released a press, in which it also claimed that there were "forced labor" and other "human rights violations" in Xinjiang region, so it suspended its offline activities in Xinjiang<sup>[i]</sup>. But how did BCI come to know that there was forced labor in Xinjiang? An investigation from Chinese media reveals that a US firm's Chinese branch was involved in this affairs, however, this branch never sent people go to Xinjiang to make serious investigation, only based web paper to make their report<sup>[ii]</sup>.

Finally, the UFLPA (Uyghur Forced Labor Prevention Act) was implemented in June 2022<sup>[iii]</sup>, which has been updated on August 19 2025, has Prohibited Xinjiang products from entering the US market.

From the above account, it can be seen that the so-called forced labor of cotton workers in Xinjiang is completely nonsense! Following, based on the information I have gathered in Xinjiang, I would like to share some insights with a few photos to let you know reality.

Concerning the original narrate about Uyghur people forced to pick up cotton in the fields, this is totally unacceptable. As I have several times to see cotton plantation and picking up processes in Alaer, Awati, Bachu and Shaya counties in Xinjinag, which is mainly mechanized operation. Attached photo one was taken by author in October 2025, which indicated Xinjiang's cotton planting and picking up processes are mostly (more than 90%) using machines. Where is there a need for forced labor to pick cotton in Xinjiang of China? Such story from US politicians, is it related to their knowledge about working conditions of black slaves on American cotton plantations several hundred years ago?



*Figure 1:* Photo one was taken in October 2025, which indicated cotton rolls have been put on a truck from cotton field in Xinjiang.



*Figure 2:* Photo two, it indicates that picking up cotton machine in cotton fields in Xinjiang<sup>[22]</sup>. These machines are mostly made in China, 90% of the cotton farming process are of mechanization.

So my opinion is that those people out off China have few knowledge about China, or some of them purposely want to blot out China. The politicians to make UFLPA using its "guilty until proven innocent" legal presumption, it is purely a disruptive impact on global supply chains, and seriously violate international trade principles. The true intention of these politicians is to use this seemingly moral concept to conceal their motives for hindering China's development.

By the way, as I know that Xinjiang Uyghor people under central government policy support and local government real efforts, all get off poverty and lived happy life in everywhere in Xinjiang. Xinjiang has already overcome the threat of terrorism and the society is very stable. Some foreign politicians have malicious attempts to make use of Xinjiang's Uyghor related terrorism issues to hinder the development of Xinjiang have failed.

<sup>[22]</sup> Source: [http://news.cnr.cn/native/gd/20251015/t20251015\\_527396064.shtml](http://news.cnr.cn/native/gd/20251015/t20251015_527396064.shtml), to pick up cotton in Xinjiang Anjihai county field in October 2025.

### **3. Key Development Needs of Xinjiang's Textile and Clothing Industries**

Despite Xinjiang has developed its textile industry relatively well, the industry still faces several needs that should be met for future development.

#### **3.1. Need to Strengthen the Downstream Sector**

Current State: Xinjiang is still stronger in midstream sectors (like spinning yarn) than in final product manufacturing. So, for better supply chain thinking, there is a strong need to attract and develop clothing, home textile and high-end fabric production firms. The goal is to keep more of the value-added textile production within Xinjiang instead of just exporting raw yarn or fabrics.

Comparatively speaking, Xinjiang's spinning, weaving and knitting capacity is quite high, however, the dyeing and finishing processing capacities are relatively weak, which is also hindered by the shortage of water resources and the higher environmental protection requirements in arid areas. Thus, Xinjiang does need new high technologies, especially innovative solutions related with less water or no water dyeing technology. Also concerning clothing supply chain, regarding to textile accessories and processing supportive services, there are still less developed than China's eastern areas. So all kinds of textile-related SMEs, whether from China or from abroad, are warmly welcomed to develop in Xinjiang.

#### **3.2. Need for Logistics and Market Access Solutions**

Xinjiang has very big space taking up one-sixth of total China's territory and is about 3500-5000 kilometers to Beijing and Shanghai as well as China's main coastal consumption centers and ports results in high transportation costs and longer delivery times. Even China has very effective logistic system (railway and highways), Xinjiang's goods to Eastern cities usually need 5-7 days, which reduce consumer's interests to order textile and other goods from Xinjiang.

So there is continued investment needs in logistics infrastructure and leveraging Xinjiang's position as a core hub for the "Belt and Road Initiative" to open up and further develop markets in Central Asia, West Asia, and Europe.

#### **3.3. Need for Brand Building and Innovation**

The Xinjiang's textile industry is largely production-oriented, functioning as a manufacturing base for brands from Eastern China or abroad. It lacks its own influential consumer brands.

So there is need to foster local Xinjiang brands, investing in design talent, and moving up the value chain from basic manufacturing to branded, high-value products. Very importantly, all Xinjiang textile and clothing industry do need to develop innovative technology, pay more attention to environmental protection and so on, also has the needs to cooperate with domestic and international partners, such as from European region, Serbia, Hungary, Romania, Turkey and so on are all ideal potential partners.

#### **3.4. Need for a Stable and Skilled Workforce**

While job creation is a success, there can be issues with employee retention and skill levels. So, there is big need to enhance vocational training programs to improve productivity and product quality. Creating a stable, long-term workforce is crucial for attracting more sophisticated investments. In recent years, Xinjiang has newly set up several textile and clothing vocational schools such as in Alaer, Aksu and Shaya county, and also set up textile colleges in Tarim University and Xinjiang University.

#### **3.5. Need to deal with the challenge from International politically suppression**

The above mentioned so called "Xinjiang cotton" issue has led to international trade restrictions and risks due to concerns over forced labor. As of August 2025, U.S. Customs and Border Protection (CBP) has detained over \$3.67 billion worth of shipments under its UFLPA<sup>[iv]</sup>, mainly from China, severely disrupting legitimate business operations.

In this case, there is need for Xinjiang textile and clothing industry (not only this two sectors but also other sectors) to focus on expanding domestic and "friendly country" markets (e.g., BRI partners). Chinese firms do think that there are plentiful countries especially in central Asia, west Asia and Eastern Europe as well as African and Southern American countries willing to do textile and clothing as well as other businesses with Chinese suppliers, or via international trade, or via web-ways such Taobao.com and Alibaba.com, or other web

means. So there are great needs to cultivate e-commerce talents in various countries and to cooperate with Chinese suppliers.

Concerning directly deal with UFLPA, there is also a need to pay more attention for Chinese firms to deal with both China and US law and regulations properly, to know clearly some exemption clause with Chinese "Blocking Measures" in specific business issues<sup>[v]</sup>. More importantly there is need to continue diplomatic efforts and make reasonable explanation in international stages. Also China does welcome more people including more medias to visit China to understand China's real development and advanced social system, to know Xinjiang people including Uyghor people's happy life. Finally all countries in the world should understand each other to give up such misunderstanding like UFLPA that is just a US domestic act, instead, it also needs to have a international labor right protection consensus with the related regulations, and so on, to realize truly human community with a shared future!

#### **4.Summary**

In summary, Xinjiang's textile industry is a large-scale, policy-driven hub with a solid foundation in raw materials and midstream production. Its future growth depends on:(1) moving downstream, to become a full-chain manufacturer of finished products, (2) going global via BRI: turning its geographical "disadvantage" into a logistic advantage for Eurasian markets, (3) adding value: transitioning from a low-margin contract manufacturer to an innovative, brand-savvy industry.

Under such circumstances, the future of the textile and clothing industry in Xinjiang will be even more prosperous. There will also be more cooperation opportunities between Xinjiang as well as other regions of China and Europe as well as other parts in the world, not only for textile and clothing industries but also for other more industries.

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## **TECHNOLOGICAL ENGINEERING STUDY PROGRAMS IN THE REPUBLIC OF SERBIA: AN OVERVIEW AND ANALYSIS**

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### **ABSTRACT**

*Technological engineering encompasses a wide range of scientific and professional disciplines. These disciplines focus on the development, optimization, and application of technological processes across various branches of the economy, including the chemical, food, textile, pharmaceutical, biotechnology, energy-environmental, mechanical, and materials industries. This paper presents an overview of higher education institutions and study programs in the area of technological engineering in the Republic of Serbia. The study programs, their duration and competencies that students acquire will be analyzed.*

**Key words:** technological engineering, study programs, higher education

### **INTRODUCTION**

In the legislation of the Republic of Serbia, technological engineering presents a separate scientific area within the educational-scientific field of technical and technological sciences (Law of Higher Education, 2017; National Council for Higher Education, 2017). In order to develop, optimize and apply technological processes in industry, technological engineering integrates principles from chemistry, physics, biology, mathematics, and computer science. Technological engineering's primary goal is optimal control of matter and energy transformations, while simultaneously improving production efficiency and preserving resources. Based on that, technological engineering has an important role in the development of modern production systems, energy, environmental protection, and innovations in the areas of materials, food technology, chemistry and biotechnology.

The development of technological engineering in Serbia is closely linked to the country's industrial growth and the development of technical education during the 20th century. Its origins can be traced back to the establishment of the Faculty of Technical Sciences in Belgrade in 1905. The period from 1905 to 1924 marked the preparatory phase for the introduction of specialized education for technological engineers, driven by the growing need for chemical and technological training of future engineers. During this time, at the Mechanical-Technical Department of the Faculty of Technical Sciences, the first permanent teaching staff was appointed and courses in technological subjects were introduced. With the amendment of the Regulation of the Faculty of Technical Sciences, University of Belgrade on November 16th, 1925, a separate Department of Technology was established alongside the three existing departments (Faculty of Technology and Metallurgy in Belgrade, 2025).

After World War II, the process of rapid industrialization created a strong demand for the education of qualified professionals. This led to the establishment of the Faculty of Technology, University of Belgrade in 1948, and later the Faculty of Technology and Metallurgy, University of Belgrade in 1967- the first higher education institutions in the Republic of Serbia specializing in chemical processes and materials technology. In the following decades, the network of educational institutions in this area expanded, with the establishment of the Faculty of Technology in Novi Sad (1959) (Faculty of Technology in Novi Sad, 2025) and the Faculty of Technology in Leskovac (1979) (Faculty of Technology in Leskovac, 2025), as well as the development of technological engineering study programs in Bor (Technical Faculty in Bor, 2025), Zrenjanin (Technical Faculty "Mihajlo Pupin" in Zrenjanin, 2025), Priština (Faculty of Technical Sciences in Priština, temporarily settled in Kosovska Mitrovica, 2025) and other places (University of Criminal Investigation and Police Studies in Belgrade, 2025; Faculty of Agriculture in Belgrade, 2025; Faculty of Applied Sciences in Niš,

2025; Agronomy Faculty in Čačak, 2025; Faculty of Technical Sciences in Čačak, 2025; The Academy of Applied Studies Polytechnic in Belgrade, 2025; Higher Technical School of Professional Studies in Zrenjanin, 2025; Academy of Professional Studies South Serbia in Leskovac, 2025; Academy of Applied Studies Šabac, 2025; Toplica Academy of Applied Studies in Prokuplje, 2025; Academy of Technical-Educational Vocational Studies in Niš, 2025; Academy of Technical and Artistic Professional Studies in Belgrade).

In the early 2000s, with the implementation of the Bologna Process, technological engineering studies in Serbia have been harmonized with European standards through the introduction of a system of bachelor's, master's, and doctoral studies, as well as the application of the ECTS credit system (Law of Higher Education, 2017). This reform enabled greater program flexibility, international recognition of diplomas, and improvement of teaching quality, but at the same time, it also revealed challenges in terms of curriculum modernization and insufficient connection with the economy. The aim of this paper is to provide an overview and analysis of accredited studies in the area of technological engineering in the Republic of Serbia, while considering their specificities, challenges, and opportunities for improvement in the context of modern educational and industrial needs.

## **STUDIES OF TECHNOLOGICAL ENGINEERING IN SERBIA**

The Law on Higher Education of the Republic of Serbia defines the types of studies, qualification levels, and the accreditation system for study programs, and establishes the existence of academic studies, where study programs are focused on scientific research, and applied (professional) studies, where study programs are focused on the practical application of knowledge (Law on Higher Education, 2017).

Academic studies are conducted by universities, faculties, and colleges of academic studies, with the aim of providing theoretical, research and professional competencies. On the other hand, applied studies are offered by academies and colleges of applied studies, and they are focused on the practical implementation of knowledge in industry.

Each course within a study program is assigned a specific number of ECTS credits, and the total scope of the study program is described as the sum of those credits. A total of 60 ECTS corresponds to the average total student workload equivalent to a 40-hour working week during one academic year. First-cycle studies include undergraduate academic studies (ranging from 180 to 240 ECTS), undergraduate applied studies (180 ECTS), and specialist applied studies (at least 60 ECTS). Second-cycle studies comprise master academic studies (ranging from 60 to 120 ECTS), master applied studies (at least 120 ECTS), and specialist academic studies (at least 60 ECTS). Third-cycle studies consist of doctoral academic studies (at least 180 ECTS).

The scientific area of Technological Engineering belongs to the educational-scientific field of Technical and Technological Sciences. According to the Rulebook on the List of Professional, Academic, and Scientific Titles (National Council for Higher Education, 2023), accredited programs in technological engineering provide the opportunity to obtain the following degrees:

- Engineer of Technology (undergraduate academic studies, 180 ECTS),
- Graduate Engineer of Technology (undergraduate academic studies, 240 ECTS),
- Graduate Engineer of Technology – Nutritionist (undergraduate academic studies, 240 ECTS),
- Master Engineer of Technology ( $180 + 120 = 300$  ECTS credits or  $240 + 60 = 300$  ECTS),
- Specialist Engineer of Technology ( $300 + 60 = 360$  ECTS),
- Doctor of Science – Technological Engineering ( $300 + 180 = 480$  ECTS),
- Applied (Professional) Engineer of Technology (undergraduate applied studies, 180 ECTS),
- Specialist Applied Engineer of Technology (specialist applied studies,  $180 + 60 = 240$  ECTS),
- Master Applied Engineer of Technology (master applied studies,  $180 + 120 = 300$  ECTS),

In accordance with the law, the accreditation of study programs is conducted by the National Entity for Accreditation and Quality Assurance in Higher Education (National Entity for Accreditation and Quality Assurance in Higher Education, 2025). The accreditation procedure ensures that a higher education institution and its study programs meet the defined standards and that the institution is authorized to issue official diplomas in accordance with the law.

Technological engineering studies in Serbia are clearly defined within the legal framework, with precisely defined levels and degrees, which ensures their compliance with European standards and the needs of the labor market. However, challenges remain in modernizing the curriculum, improving laboratory capacities and strengthening cooperation with the industrial sector in order to adequately prepare students for modern industrial and research requirements.

## OVERVIEW AND ANALYSIS OF STUDY PROGRAMS

Table 1 presents the undergraduate academic study programs in the area of Technological Engineering offered in Serbia, each carrying 240 ECTS credits. For each program, the table provides the name of the faculty, the study program title, and the number of enrolled students.

*Table 1: Undergraduate academic study programs.*

Higher education institution	Study Program	Number of Students
Faculty of Technology and Metallurgy, University of Belgrade	Chemical Engineering	150
	Biochemical Engineering and Biotechnology	110
	Environmental Protection Engineering	60
	Materials Engineering	60
Faculty of Technology, University of Novi Sad	Food Engineering	95
	Biotechnology	61
	Chemical Engineering	48
	Pharmaceutical Engineering	38
	Materials Engineering	22
Faculty of Technology in Leskovac, University of Niš	Technological Engineering	120
Technical Faculty in Bor, University of Belgrade	Technological Engineering	60
Technical Faculty "Mihajlo Pupin", Zrenjanin	Textile Engineering	50
Faculty of Technical Sciences, University of Priština, temporary settled in Kosovska Mitrovica	Technological Engineering	32
Military Academy, Belgrade	Materials and Protection Engineering	20
University of Criminal Investigation and Police Studies, Belgrade	Forensic Engineering	25
Faculty of Agriculture, University of Belgrade	Food Technology	16
Faculty of Applied Sciences, University of Niš	Modern Food Technologies	20
Agronomy Faculty Čačak, University of Kragujevac	Food Technology	40

Table 2 presents the undergraduate applied (professional) study programs offered in Serbia, each carrying 180 ECTS credits, organized by faculty.

*Table 2: Undergraduate applied (professional) studies.*

Higher education institution	Study Program	Number of Students
Faculty of Technical Sciences Čačak, University of Kragujevac	Graphic Techniques	44
	Textile Engineering and Design	40

The Academy of Applied Studies Polytechnic, Belgrade	Graphic Engineering	60
	Sustainable Technologies	40
	Food Engineering and Safety	60
	Textile Engineering	60
Faculty of Technical Sciences Čačak, University of Kragujevac	Graphic Techniques	44
	Textile Engineering and Design	40
Higher Technical School of Professional Studies, Zrenjanin	Technological Engineering	50
Academy of Professional Studies South Serbia, Leskovac	Textile Engineering	22
Academy of Applied Studies, Šabac	Food Technology	22
Toplica Academy of Applied Studies, Prokuplje	Food Technology	40

Table 3 presents the master academic study programs (60 or 120 ECTS) offered in Serbia, showing the faculty, study program name, and number of enrolled students.

*Table 3: Master academic study programs.*

Higher education institution	Study Program	Number of Students
Faculty of Technology and Metallurgy, University of Belgrade	Chemical Engineering	80
	Biochemical Engineering and Biotechnology	55
	Environmental Protection Engineering	40
	Materials Engineering	25
	Digital Process Engineering	30
Faculty of Technology, University of Novi Sad	Food Engineering	45
	Biotechnology	36
	Chemical Engineering	27
	Pharmaceutical Engineering	18
	Materials Engineering	9
Faculty of Technology in Leskovac, University of Niš	Technological Engineering	48
Technical Faculty in Bor, University of Belgrade	Technological Engineering	60
Technical Faculty "Mihajlo Pupin", Zrenjanin	Textile Engineering	16
Faculty of Agriculture, University of Belgrade	Food Technology	96
University of Criminal Investigation and Police Studies, Belgrade	Forensic Engineering	40
Faculty of Applied Sciences, University of Niš	Modern Food Technologies	10
Agronomy Faculty Čačak, University of Kragujevac	Food Technology	16
Faculty of Technical Sciences, University of Priština, temporary settled in Kosovska Mitrovica	Chemical Engineering	24

Table 4 presents the master applied (professional) study programs offered in Serbia, each carrying 120 ECTS credits, and organized by faculty.

*Table 4: Master applied (professional) studies programs.*

Higher education institution	Study Program	Number of Students
The Academy of Applied Studies Polytechnic, Belgrade	Graphic Production	16
	Food Technology	16

Higher Technical School of Professional Studies, Zrenjanin	Technological Engineering	16
Academy of Professional Studies South Serbia, Leskovac	Textile Engineering	8
Academy of Technical-Educational Vocational Studies, Niš	Technological Engineering	16
Academy of Technical and Artistic Professional Studies in Belgrade	Textile Engineering	32

Table 5 presents the specialist academic study programs offered in Serbia, each carrying 60 ECTS credits, and organized by faculty.

*Table 5: Specialist academic study programs.*

Higher education institution	Study Program	Number of Students
Faculty of Technology, University of Novi Sad	Food Microbial Safety	18
	Cosmetic Technology	8
Faculty of Agriculture, University of Belgrade	Food Technology	16

Table 6 presents the doctoral academic study programs offered in Serbia, each carrying 180 ECTS credits, and organized by faculty.

*Table 6: Doctoral academic study programs.*

Higher education institution	Study Program	Number of Students
Faculty of Technology and Metallurgy, University of Belgrade	Chemical Engineering	30
	Materials Engineering	25
	Biochemical Engineering and Biotechnology	15
Faculty of Technology, University of Novi Sad	Food Engineering	21
	Biotechnology	15
	Pharmaceutical Engineering	15
	Chemical Engineering	15
	Materials Engineering	10
Faculty of Technology in Leskovac, University of Niš	Technological Engineering	15
Technical Faculty in Bor, University of Belgrade	Technological Engineering	8
Faculty of Technical Sciences, University of Priština, temporary settled in Kosovska Mitrovica	Technological Engineering	5
University of Criminal Investigation and Police Studies, Belgrade	Forensic Engineering	40
Faculty of Agriculture, University of Belgrade	Food Technology	32

## CONCLUSIONS

The overview of higher education institutions and study programs in the area of technological engineering in the Republic of Serbia was presented in this paper. The study programs were analyzed, their duration and competencies that students acquire, with the aim of providing a clear picture of technological engineering education in Serbia.

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## **THE IMPACT OF TEXTILE MATERIAL QUALITY ON THE OPTIMIZATION OF CUTTING PATTERNS EFFICIENCY**

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### **ABSTRACT**

*This paper follows the technological process of marker making for men's keper trousers in „Shooter clothing company“. The research are done on the given model is described according to the current production state, with proposals for optimizing specific production parameters: testing textile, pattern correction, marker making and cutting. The influence of textile material quality on the optimization of marker efficiency was examined. Increasing marker utilization is conditioned by good organization of textile testing prior to fabric spreading in cutting lays. The end goal is to find optimal combinations of textile material parameters that enables maximum marker utilization and minimum waste in production, which is very important for the sustainability and economic efficiency of the textile industry.*

*Fast fashion requires fast and efficient work, as well as adaptation to market demands. Development of various computer software packages specialized for the needs of the textile industry has made this possible. In this paper use of the OptiTex packet program will be shown, specifically pattern creation and marker making.*

**Key words:** textile materials, cutting patterns, quality, technical preparation of garment production, CAD system

### **1. INTRODUCTION**

Textile testing represents a direct application of engineering knowledge for the purpose of determining various properties of textile materials. The quality of textile materials is assessed through textile testing. The quality of a product implies the set of all properties that characterize it in technical and functional terms (Ašanin M., 2009.)

The quality of a textile product is influenced by:

- the selection of raw materials (quality of raw materials),
- the selection of secondary materials (finishing, dyes, etc.),
- selection of technological processes (modernity of machines and equipment),
- human factors (training and qualifications), and
- working conditions (climate, lighting, temperature).

This paper focuses on the testing of aesthetic characteristics of fabrics (as final products). It addresses the examination of textile material properties (fabrics), as well as the testing of finished products made from these fabrics, using the example of production for the domestic fashion brand Shooter. The principles and procedures of testing in an accredited laboratory cooperating with the production company, in accordance with the SRPS EN ISO standard and with a long tradition in textile, leather, and footwear testing and quality control, are presented. Both physical and chemical tests are performed.






In addition, the paper deals with the principles and methods of marker making for garment parts using a modern computer system, taking into account the physical and quality properties of fabrics that were previously tested and that directly affect work speed, quality, marker utilization percentage, and the quality of the finished product.

The paper follows the design and construction preparation for a model of men's keper trousers that has proven to be highly demanded on the market and is repeated from season to season with minor modifications. A significant time saving is achieved through a standardized adopted model, if textile testing for the model shows satisfactory results because material is stable, does not shrink beyond permitted limits, and has good color durability, serial production can begin very quickly without any corrections or repeated testing of the material and the prototype (counter-sample) of the required model.

## 2. TEST REPORT ON KEPER FABRIC

*Tabel 1. Laboratory testing report on fabric*

Test element	Testing method	Unit	Declared values	Obtained values
1. MASS PER UNIT AREA	ISO 3801:1977-method 5	g/m <sup>2</sup>	200±5%	209,6
2. MAXIMUM TENSILE FORCE	SRPS EN ISO 13934-1:2015	N		
- in warp direction			min 900	935,0
- in the filling direction			min 300	308,7
3. WIRE DENSITY	ISO 7211-2:1984	ž/10cm		
- number of warp threads			min 420	450
- number of weft threads			min 200	230
4. YARN FINESS	SRPS ISO 7211-5:2005	tex		
- warp			27x1±6%	29,1x1
- filling			27x1±6%	29,4x1
5. RAW MATERIAL	SRPS EN ISO 1833-2:2020 SRPS EN ISO 1833-11:2018	%		
- COTTON			98±3	98,3
- ELASTANE			2±3	1,7
6. DIMENSIONAL CHANGE UPON WASHING ON 30°C	ISO 5077:2007 SRPS EN ISO 3759:2012 SRPS EN ISO 6330:2022 washing process 3N, drying process C	%		
- along the length			±2	-2,0
- across the width			±2	-2,0
7. COLOR FASTNESS TO: COTTON / WOOL			CHANGE/TRANSFER	ONTO:
- light	SRPS EN ISO 105-B02:2015	rating	min 4	4
- wash on 30°C	SRPS EN ISO 105-C06:2016	rating	min 4	4/4
- dry cleaning	SRPS EN ISO 105-D01:2012	rating	min 4	4/4/4
- dry rubbing	SRPS EN ISO 105-X12:2017	rating	min 3	4-5/4-5
- wet rubbing	SRPS EN ISO 105-X12:2017	rating	min 3	4/4
8. CARE INSTRUCTION: according to SRPS EN ISO 3758:2014				

- wash		Maximum washing temperature 30°C, normal process
- bleaching		Bleaching not allowed
- drying		Drying not allowed in drum
- ironing		Ironing with maximum temperature of 110°C
- dry cleaning		Professional dry cleaning in tetrachloroethylene and all solvents listed for symbol F, normal process

### 3. PATTERN MARKER DEVELOPMENT

A pattern marker is a set of all pattern elements, i.e., garment pieces, that are rationally arranged in the warp direction of the material on a defined surface. To achieve better material utilization, multiple identical or different garment sizes are often included in one pattern marker. Pattern markers are created separately for each type of material that makes up a garment (main fabric, lining, interlining, pocket lining, etc.). Pattern markers are placed on the top layer of the cutting lay and enable the cutting of material in the lay.

Pattern markers in the garment industry can be single size or multi size, depending on production needs and requirements. Creating a pattern marker requires careful planning and consideration of various factors.

It is important to choose an appropriate method of spreading the cutting lay, which may include open width materials, folded materials, or loop materials. Each of these requires a specific approach to marker making in order to achieve the desired result. This is done to maximize material utilization and ensure efficient production.

The pattern marker maker must have accurate information about the working widths of fabric rolls, possible color variations or differences between rolls, in order to determine whether the same model must be arranged on several different widths and to specify which color (roll) is used for which pattern marker. They must also know the length of the cutting table on which the order will be cut, as well as the approximate number of layers in the cutting lay, which largely depends on the type, properties, and thickness of the material, as well as the equipment of the cutting room machinery (knife height). During pattern marker development, constructors consider all these factors to ensure that the marker corresponds to the garment design and functionality. This process requires expertise and experience to achieve optimal results.

The use of advanced CAD systems, such as Optitex in Shooter, enables precise planning and development of pattern markers, with the possibility of simulating fabric behavior and spreading. This allows efficient material usage, waste reduction, and improved productivity in garment production.

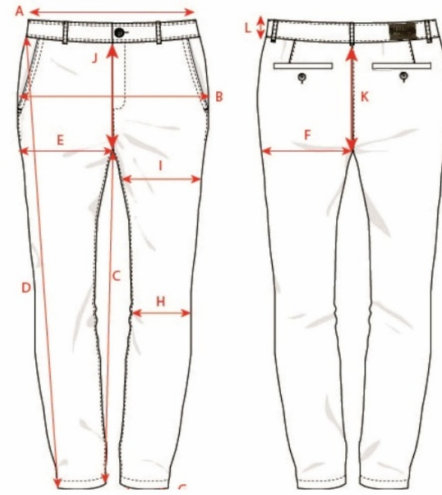
#### 3.1. Model description MP 48260-01

Classic men's keper trousers with waistband, regular length, fastened with a patent closer and one button at the waistband. On the front there are slanted pockets, double stitched edges. On the back there is a single dart and welt pocket with one welt, width 1.5cm, buttonhole and button. The waistband has five belt loops.

It is important to be familiar with the equipment of the workshop's machinery that will produce the model, so that all cut pieces are made in the appropriate dimensions required by the sewing attachments and automatic machines. Belt loops for men's trousers are cut in strips measuring 3.8cm × 80cm, and the waistband is cut to a width of 6.9cm, extended by 9cm on both sides beyond the finished waistband length to allow for feeding into the machine. When the back pocket has a single welt (finished width of 1 cm or 1.5cm), the welt is cut to a width of 6cm, and the pocket facing beneath the welt is cut to a width of 7cm.

<b>TABEL OF TROUSER SIZE CHART</b>		
	<b>Base size:</b>	<b>32</b>
<b>A</b>	Waist circumference	87
<b>B</b>	Hips circumference	110
<b>C</b>	Leg length (inseam)	87,5
<b>D</b>	Pant length (waist band not included)	110
<b>E</b>	Hip width on front	29
<b>F</b>	Hip width on back	37
<b>G</b>	Hem width 1/2	17
<b>H</b>	Knee width 1/2	20
<b>I</b>	Thigh circumference 1/2	30,5
<b>J</b>	Front rise (waist band not included)	24
<b>K</b>	Back rise (waist band not included)	35
<b>L</b>	Waist band height	4,5
*All measurements in cm		

Table 2. Tabel of trouser size chart - base



size 32 with a technical sketch of the men's trouser model

### 3.2. Computer based pattern making

The advantages of creating pattern layouts using computers compared to manual drafting are numerous. The use of computer software makes it possible to achieve higher quality pattern layouts, as accuracy and precision can be easily monitored and adjusted. In addition, the pattern making process is significantly faster, since the software automatically performs many operations such as pattern nesting, size grading, and generation of output data. This results in reduced production time and increased productivity. Workers experience less fatigue, as many routine and physically demanding tasks are handled by the computer. Additionally, computer systems enable better utilization of pattern layouts, as different pattern versions can be generated and various fabric layouts can be tested, contributing to the optimization of material consumption. All these advantages make computer based pattern making more efficient, precise, and economical compared to manual methods. (Paunović D., Čolović G., 2004.)

At the company “Shooter”, pattern nesting is carried out using specialized software called Marker 12. The software enables optimization of pattern placement on the fabric in order to maximize the use of available space and minimize material consumption. In addition, the program provides a visual display of the final marker, which makes easier evaluation and verification of the pattern layout before proceeding to physical production. Along with automatic pattern nesting, Marker 12 also allows manual adjustment of pattern placement and customization according to specific production requirements. This sophisticated software offers significant benefits in terms of savings in time, material, and resources, thereby contributing to efficiency and competitiveness in the garment industry.

### 3.3. Work order

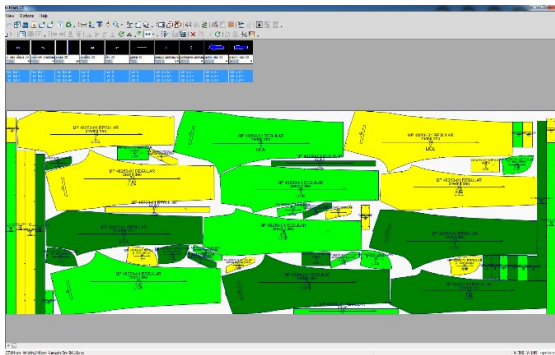
The work order contains basic information about the model, a sketch or photo of the model, and data on the usable widths of the materials used for cutting the requested model. It also includes a detailed size breakdown required for production by the customer, as well as any additional notes, if applicable, and information about the workshop in which the production of the requested model will be carried out.

<b>RADNI NALOG</b>																				
BROJ:		<b>MP 48260-01R</b>																		
model:		<b>REGULAR FIT</b>																		
konstrukcija:		<b>SIM TEKSTIL-SYDNEY</b>																		
materijal:		<b>98% pamuk, 2% elasthan</b>																		
sr. sastav:		<b>ASKISS-NOVI PAZAR</b>																		
šije:																				
<b>OSNOVA</b>	30	31	32	33	34	35	36	38	40	<b>NAL</b>	<b>isk.</b>									
<b>BEZ</b>	6	4	11	8	16	15	22	22	22	18	18	22	22	14	15	3	8	134	134	
<b>CRNA</b>	4	4	38	39	46	48	50	54	56	54	20	20	56	54	50	48	40	39	360	360
<b>MASLINA</b>	4	4	36	36	40	41	48	50	48	50	12	12	54	50	46	41	36	36	320	320
																			0	0
																			0	0
																			814	814
<b>SIRINE MATERIJALA:</b>		<b>SIRINE POSTAVE:</b>																		
BEZ 146cm radna sirina		140cm																		
MASLINA 146cm radna sirina																				
CRNA 137cm radna sirina																				

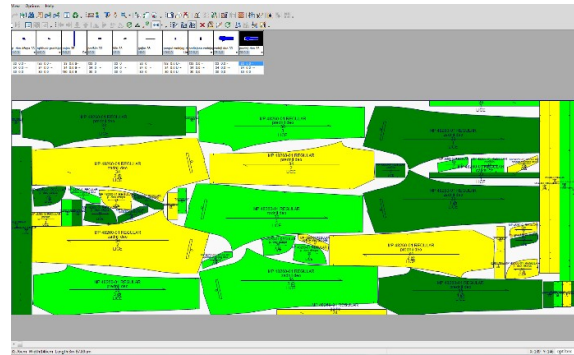
Figure 1. Work order for men's trousers  
 MP 48260-01

#### 4. ANALYSIS OF RESULTS

By analyzing the work order, the pattern maker seeks the best possible nesting solution, taking into account the fabric widths, type of material, and the quantities requested in the work order. The quantities of the model per size ordered by the customers are marked in red on the order. The number of cut pieces according to the nesting plan is indicated in blue by the pattern placer. Sizes 33, 34, and 36 will be nested together on a fabric width of 146cm for beige and olive colors. The same sizes also need to be nested on a fabric width of 137cm for black. Due to the large difference in fabric widths, it is impossible to nest all colors together. If all sizes were cut together on the narrowest width, it would result in significant material waste.



*Figure 2. Pattern layout for sizes 33-34-36-1X in a single direction on 146cm fabric width*

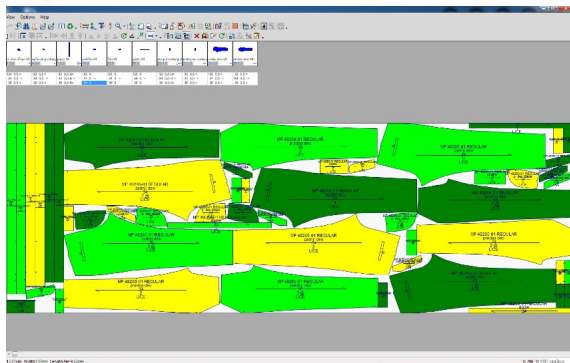


*Figure 3. Pattern layout for sizes 33-34-36-1X in two directions on 146cm fabric width*

Shown in figure 2. is the nesting of three trouser sizes in the same direction on width of 146cm, the length of pattern layout is 3m 94.11cm, with a nesting efficiency of 82,94%. The fabric consumption per piece for this layout is **1.33 m/piece**.

Regarding the efficiency of pattern utilization, any value above 80% is considered acceptable in production. Efficiency depends on the shape and size of the pattern pieces, the possibility of fitting them within the fabric width, and the number of pieces that can be accommodated in a single layout. Multi size pattern layouts are generally more efficient, if the fabric structure allows nesting in two directions (for fabrics without nap, specific prints, borders, or other production requirements), rotating a piece or size in the opposite direction can further increase efficiency and reduce the layout length. Therefore, for this work order, pattern layouts will be nested and used in two directions, as the fabric allows it.

In Figure 3, the nesting of three trouser sizes in two directions on a fabric width of 146cm is shown. Size 34 is rotated in the opposite direction to sizes 33 and 36. The length of the pattern layout is 3m 87.89cm, with a nesting efficiency of 84,27%. Fabric consumption per piece for this layout is **1.31 m/piece**. The consumption is 2 cm less per piece compared to the previous layout. While this may seem small, when calculated over production quantities, it represents a significant difference in material usage and waste, which in turn increases the product cost (for example, for a production of 1000 pieces, this difference amounts to 20m of fabric multiplied by the material cost).

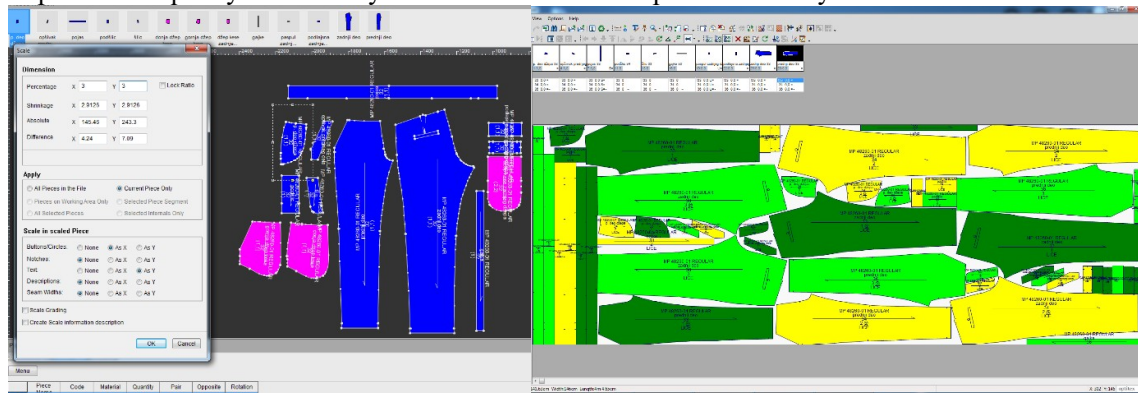


In Figure 4, the nesting of three trouser sizes in two directions on a fabric width of 137cm is shown. Size 34 is rotated in the opposite direction to sizes 33 and 36. The length of the pattern layout is 4m 9.22cm, with a nesting efficiency of 85.12%. Fabric consumption per piece for this layout is **1.38 m/piece**, which means that the consumption for the black color is 7 cm more per piece.

*Figure 4. Pattern layout for sizes 33-34-36-1X in two directions on 137cm fabric width*

Material testing showed that the fabric shrinks within normal limits, and no correction of the pattern dimensions is required.

In Figure 5, the difference in nesting is shown and correction and a 3% increase in pattern dimensions were applied. Three trouser sizes nested in two directions on a fabric width of 146cm are shown. The length of the pattern layout is 4m 4.65cm, with a nesting efficiency of 85,56%. Fabric consumption per piece for this layout is **1.37 m/piece**. For unstable material, the consumption would be as if the fabric roll width were 9 cm narrower compared to stable material. From this analysis, we can see how important the quality and stability of the fabric chosen for production truly are.



*Figure 5. Automatic pattern enlargement and pattern layout for sizes 33-34-36-1X in two directions on 146cm fabric width corrected +3%*

## 5. CONCLUSION

When nesting pattern layouts, the pattern placer takes care of many parameters that affect the quality of the nesting (requested sizes and quantities, fabric width, type of material, stability, structure, pattern...) and considering all of these factors, seeks the most efficient solution to meet the requirements of the work order and production.

Analysis of the pattern nesting results for model MP 48260-01 shows that, if the fabric allows rotation in both directions as in this case, the pattern layout length is reduced by 6.22 cm, fabric consumption decreases by 2 cm/piece, and nesting efficiency increases by 1.33%. The importance of proper fabric width is evident from the analysis of nesting the same model on a fabric roll that is 9 cm narrower. The focus should not be solely on percentage fabric utilization, because in this case, the nesting efficiency increases by 0.85%. However, the layout length is 21.33 cm longer, resulting in 7 cm more fabric consumption per piece. The significance of fabric stability (must be determined through prior testing) is reflected in the analysis of nesting the same model on a fabric with better width, but after applying a +3% pattern correction due to expected shrinkage. This results in a more efficient pattern layout of 85.56%, but with increased layout length (+16.76 cm), raising fabric consumption by 6 cm per piece. For unstable fabric, the effect would be equivalent to having a roll width 9 cm narrower compared to stable material.

Therefore, clothing manufacturers invest in high-quality fabric. Fabric that is stable, does not shrink or deform beyond acceptable limits ( $\pm 2\%$ ) during the garment production process, as well as during washing and wearing and has a proper working width. That way production process is easier, manufacturing time is shorter, productivity increases, improves the efficiency of pattern layouts, and reduces fabric consumption. So waste is minimized and result is a high-quality garment.

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## INDUSTRY 4.0 IN THE TEXTILE AND FASHION SECTOR

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### ABSTRACT

*The paper presents the concept of Industry 4.0 as the digitalization and interconnection of every machine within a company, every technological component, and practically every piece of material that passes through the textile and clothing production process. The goal of the Industry 4.0 revolution is to make the vision of the “smart textile factory” a reality. The “smart factory” enables the connectivity of innovation actors, universities and other educational institutions in the areas of procurement and distribution, as well as workforce training, public administration, and banks. Four key innovative themes that will shape the future textile and apparel industry are advanced materials, digitalization, sustainability, and new growth markets. Of great importance is the training of personnel for new jobs emerging in the Industry 4.0 revolution. Using the example of the CAD/CAM product program of the French company Lectra, the digital transformation of the apparel industry is explained in terms of strengthening brands and manufacturers from design to production.*

**Key words:** *Industry 4.0 concept, „smart factory“, digitalisation of textile and fashion industry, clothing production*

### 1. INTRODUCTION

The concept of Industry 4.0 is most commonly characterized in the literature as the fourth industrial revolution; however, there are also opinions that view this concept merely as an evolution in the application of computers in manufacturing. Nevertheless, the fact remains that Industry 4.0 has today become a global project, with the most developed industrial countries creating and implementing national programs based on this model. This indicates that global competitiveness has become the main driver of the development of this concept and that it represents a new stage in the evolution of computer application in production. The textile and fashion industry are currently on the threshold of another revolutionary transformation: the integration of Industry 4.0 into the production of textile and fashion products. For centuries, textile production has marked key milestones in industrial development, evolving from spinning machines to steam-powered looms and, more recently, to digitalization and the emergence of “smart factories.” This new wave, characterized by intelligent automation, data connectivity, and machine learning, is fundamentally changing the way textiles are produced. Smart factories are no longer merely experimental environments; today they represent a significant shift in manufacturing practices and an improvement in the way textile and fashion products are produced and brought to market. The term Industry 4.0 was first mentioned in Germany in 2011 by the Deutsche Working Group, with the aim of directing investment toward projects focused on the modernization of industry under conditions of widespread digitalization enabled by technological development. The objective was the adoption of modern work processes through the development of technology and products, as well as the need to respond to changing market demands and increasingly aggressive and numerous competition. The European Technology Platform for the

Future of Textiles and Clothing defines Industry 4.0 as the digitalization and interconnection of every machine within a company, every technological component, and every piece of material that passes through the production process. The development of Industry 4.0 requires significant investments in research, development, and education in order for the vision of a smart textile factory to become a reality. [1]

## 2. „SMART FACTORY“

Industry 4.0 aims to improve financial and market performance by reducing labor costs through the development of production infrastructure that better supports robotics and advanced automation. New generations of machines will also be more productive, resulting in fewer workers and less material waste in production lines. This will enable the networking of machines and a higher level of automation. Intelligent manufacturing will lead to lower product prices, allowing companies to attract a larger number of consumers in the market. In addition, intelligent manufacturing opens opportunities for providing additional services to customers, particularly through personalized production. This refers to the possibility of individual production for a known customer according to their specific requirements, allowing them to participate in the creation of the product. Virtual product development creates a new form of communication with customers and enables their preferences to be incorporated into the process of experimenting with new products and their design. The fashion industry is one of the most significant manufacturing sectors, generating an economy worth approximately 3 trillion dollars and contributing about 2% to the global gross domestic product (GDP). The fashion industry plays a key role in the design, production, and sale of clothing and apparel products. Therefore, the fashion sector must encourage innovation and build intelligent infrastructure through the use of digitalized technologies such as IoT, AI, blockchain, and others. These new technologies are capable of establishing sustainable industrialization due to their unique and intelligent characteristics. A report by the European Commission predicts that the use of smart clothing will become widespread in the future [2]. For this reason, innovative fabrics and garments must be modern, flexible, reliable, and smart. This can be achieved thanks to the availability of miniature electronic chips and sensors, as well as energy-efficient connectivity protocols. The concept of Industry 4.0 refers to the “smart factory,” which uses information and communication technologies to manage production and business processes in order to achieve market dominance through improved quality, lower costs, and more flexible production adapted to market needs. The smart factory is also referred to as a “learning factory.” This term is used because, in accordance with changes in the market, technology, science, and available resources, employees are continuously trained, while the enterprise system quickly adapts to new conditions [3,4]. The smart factory and its environment demonstrate the interconnectedness of innovation actors, universities and other educational institutions, industry in the areas of procurement and distribution, as well as public administration and banks. It should be emphasized that the development of innovation, and thus economic development, is based on the key role of universities, industry, and government through the creation of new institutional and social frameworks for the production, transfer, and application of knowledge [5].

In order for the “smart factory” to become a reality, it is necessary to achieve the key characteristics of the Industry 4.0 concept, which include the following [5,6]:

1. complete digitalization, computer-based monitoring and management of production and business processes, and mutual communication through M2M (Machine-to-Machine), H2M (Human-to-Machine), and M2H (Machine-to-Human) interaction. This includes enabling machines, devices, sensors, and people to connect and communicate through the Internet of Things (IoT) or the Internet of People (IoP). It is also necessary to unify machine languages, since the large number of protocols and transport media currently makes the connection and sharing of machine data extremely difficult. Today there is a wide range of machines that must achieve connectivity and communication with each other as well as with humans, given the existence of numerous different technical “languages.”

2. Comprehensive networking that includes customers and suppliers, banks, public administration, as well as research and educational institutions.
3. The capability of information systems to create virtual copies of the physical world, with object characteristics based on sensor data and the transformation of this data into information of higher practical value.
4. The ability of systems to enable humans, through information, to make decisions and resolve urgent problems within a short time, as well as the capability of cyber-physical systems to perform unpleasant, overly exhausting, and dangerous tasks.
5. The ability of cyber-physical systems to make decisions independently and perform their tasks as autonomously as possible; only in cases of exceptions, disturbances, or conflicting objectives are tasks delegated to a higher (human) level.
6. Personalized and flexible production adapted to the end consumer and the specific preferences of customers.
7. Products known as Internet of Things (IoT) devices contain computer and digital components responsible primarily for the proper functioning and maintenance of the product.
8. Market demands or new innovative solutions and inventions—from raw materials and production processes to the final product—can be implemented immediately or within the shortest possible time throughout the entire enterprise system.
9. Intensive data protection must be ensured, not only for products and production processes but also for customers, since widespread digitalization threatens privacy and may lead to potential misuse of data.

Figure 1 presents an illustration of the “Smart Factory.”

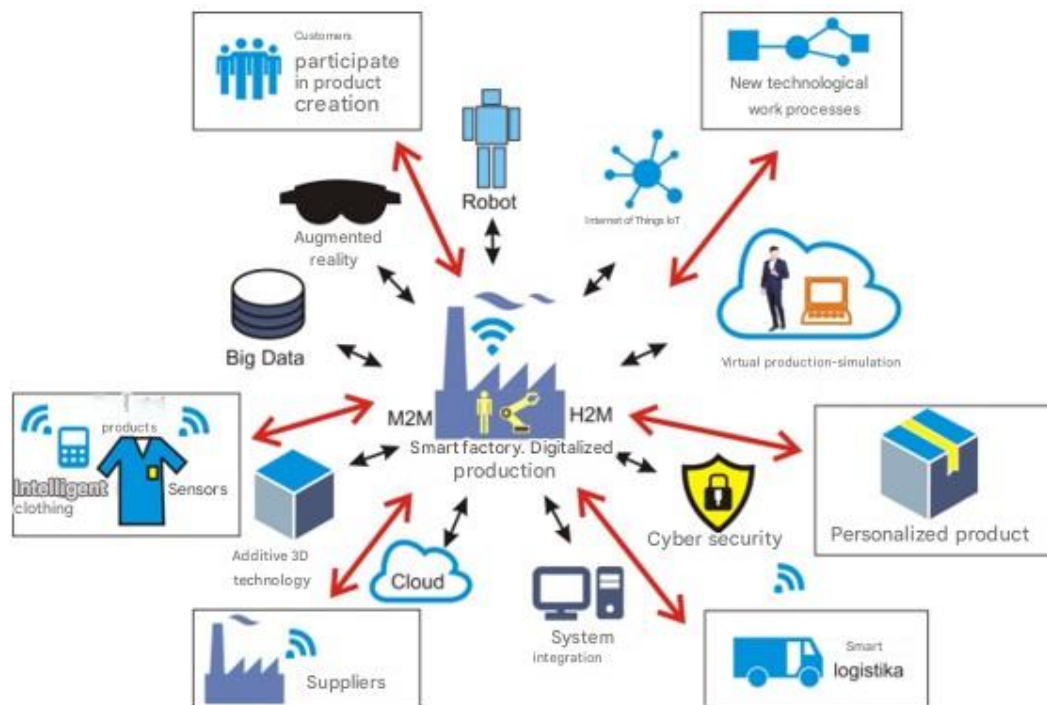
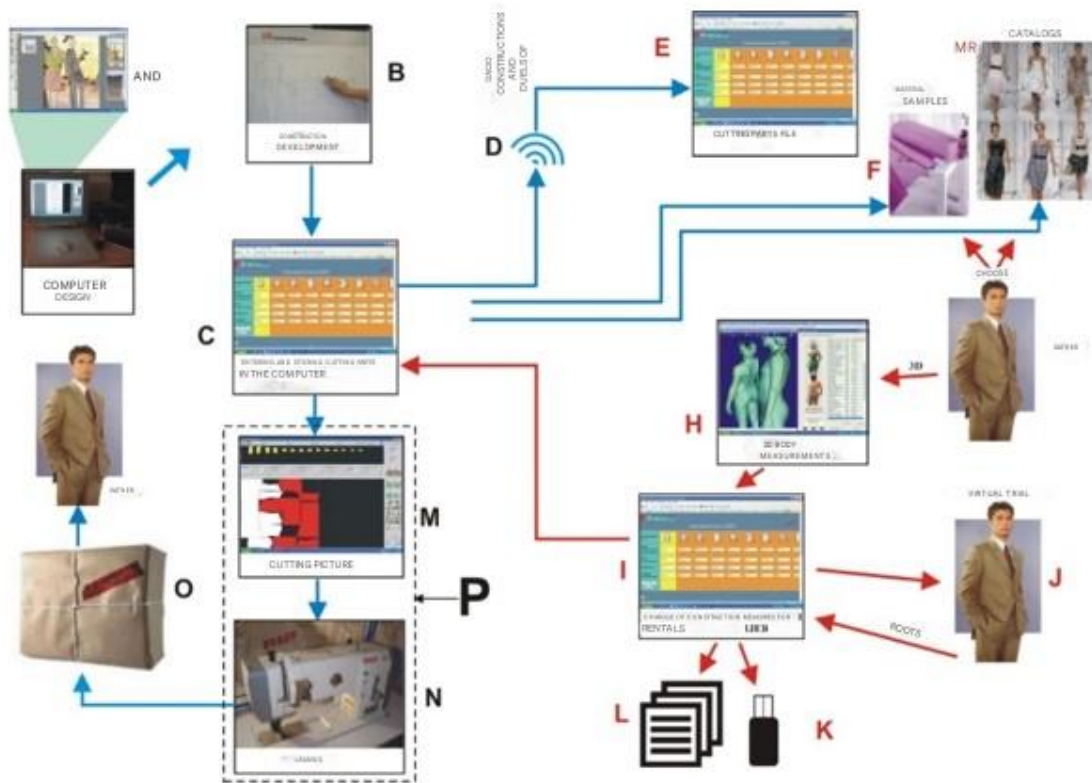


Figure 1: “Smart Factory.” [5,6]

### 3. INDUSTRY 4.0 REVOLUTION – APPLICATION IN CLOTHING PRODUCTION

Today, the automation of garment production has not yet been fully achieved, since in industrial clothing manufacturing the share of human labor in the final product ranges from 60% to 70%. However, market changes indicate that, in addition to mass production, there is an increasing demand for industrial production of made-to-measure clothing. Personalized production is emerging, aiming to meet the requirements of each individual customer. This creates a new business challenge: transforming production lines from high-volume serial production into mass customization. Mass customization refers to the production of a large number of products through the same production process but with variations between them, such as differences in dimensions (sizes), patterns, designs, and similar characteristics. This approach represents the application of the ideas and principles of Clothing Industry 4.0 [7].

An example of a currently developed system that integrates clothing design and production is partially automated and includes the following stages: automatic measurement of the customer, automatic adjustment of pattern pieces according to the customer’s measurements, a virtual fashion show, virtual fitting of the garment, correction of identified deficiencies, partial automation of garment production, and delivery of the finished clothing product to the customer [8].



**Figure 2:** Process of garment production from design to the final product for an individual customer [8].

Four key innovative themes that will shape the future of the textile and apparel industry are advanced materials, digitalization, sustainability, and new growth markets. Of great importance is the training and qualification of personnel for new jobs emerging in the Industry 4.0 revolution [9,10]. One of the good examples used to explain the digital transformation of the apparel industry in strengthening brands and manufacturers—from design to the production of textile and fashion products—is the

CAD/CAM product program of the French company Lectra. In particular, one form of production digitalization that enables the transition from mass production to individual (personalized) production is offered by the company Lectra. The difference in the production process between mass production and individual production is shown in Figure 3 [4].



Figure 3: Mass and individual production [4]

The key development segment offered by Lectra is a digitalized cutting department. This new cutting department solution is capable of receiving individual customer orders consisting of only a single garment item within a production series. The production system makes it possible to meet all customer requirements for the production of a single garment with the desired design, clothing size, and other specifications. Processing all the data related to the garment product requested by customers requires a very powerful computer, which individual companies often cannot possess on their own. For this reason, Lectra uses “the cloud,” that is, a shared computing center for data processing that is geographically distant from the companies. All companies connect to this center via the internet, where the processing of their data is carried out. The processed data are then returned to the company very quickly and used for the realization of the production of the desired garment according to the technical specifications defined by the customer [5].

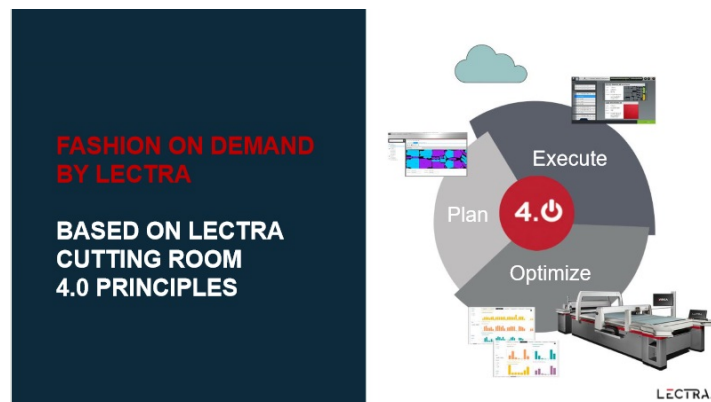


Figure 4: Lectra’s tailoring production based on 4.0 principles [4]

A new solution with activities, offered by Lectra, is shown in Figure 5.

**HOW FASHION ON DEMAND CONNECTS YOUR ACTIVITIES**

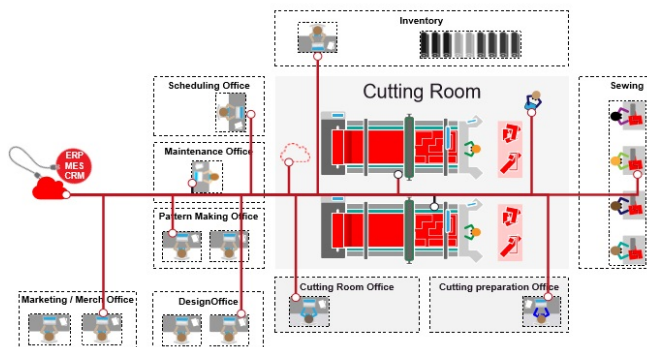


Figure 5: Lectra's line with activities for personal production [4]

The core segment of the new digital solution offered by the Lectra company is their tailoring machine shown in Figure 6.

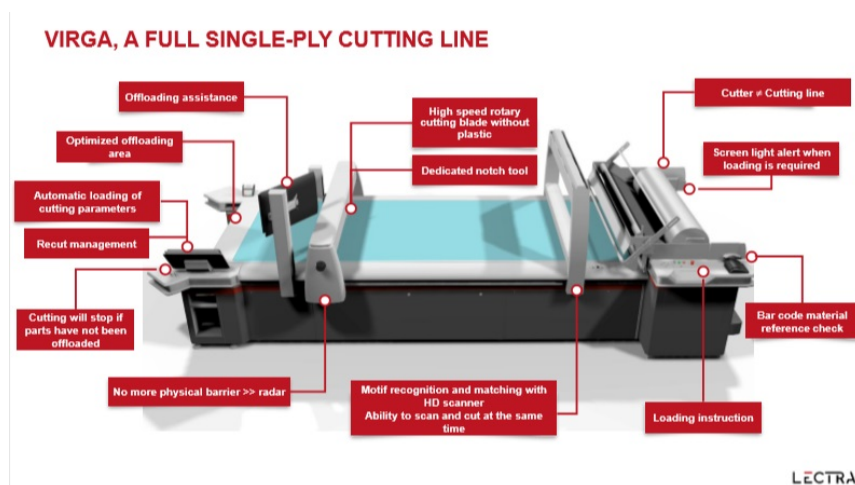


Figure 6: Lectra's Cutter 4.0 [4]

**4. CONCLUSION**

The concept of Industry 4.0 is most commonly characterized in the literature as the fourth industrial revolution. However, there are also views that consider this concept merely as an evolution in the application of computers in manufacturing. The Industry 4.0 revolution represents the digitalization and interconnection of every machine within a company, every technological component, and practically every piece of material that passes through the production process of textile and clothing manufacturing. The goal of the Industry 4.0 revolution is to turn the vision of the “smart textile factory” into reality. The “smart factory” enables the connectivity of innovation actors, universities and other educational institutions in the areas of procurement and distribution, as well as workforce training, public administration, and banks. Four key innovative themes that will shape the future of the textile and apparel industry are advanced materials, digitalization, sustainability, and new growth markets. Of great importance is the training and qualification of personnel for new jobs emerging in the Industry 4.0 revolution. Using the example of the CAD/CAM product program of the French company Lectra, the digital transformation of the apparel industry is explained in terms of strengthening brands and manufacturers from design to production.

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## **AN EXPLORATION OF MODULAR FASHION WITHIN THE FRAMEWORK OF A CIRCULAR FUTURE ECONOMY**

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### **ABSTRACT**

*Modular fashion is a design approach based on adaptability, functionality, and personalization through garments with interchangeable or detachable components. It enables users to modify clothing for different occasions and needs, extending product lifespan and reducing consumption. However, most existing solutions still rely on newly produced textiles, which continue to impact natural resources.*

*This study proposes a shift toward sustainable modular fashion through the upcycling of textile waste, deadstock fabrics, and discarded garments. By transforming existing materials into modular and multifunctional designs, the approach reduces waste and improves resource efficiency. Upcycling diverts textiles from landfills while creating new functional value, lowering the environmental impact of fashion production.*

*The research highlights modular design strategies that demonstrate how upcycled materials can be used to develop adaptable and sustainable fashion products. Integrating modularity with upcycling supports a circular fashion economy in which waste is redefined as a resource and sustainable consumption is encouraged. The proposed framework offers a scalable solution for reducing textile waste in the fashion industry.*

**Key words:** modular fashion, upcycling, sustainability, circular economy, textile waste.

### **INTRODUCTION**

Modular fashion represents an innovative approach within the fashion industry that is grounded in the principles of adaptability, functionality, and personalization through the design of garments and accessories with interchangeable or detachable components. This concept enables users to flexibly adjust their wardrobe according to different occasions, seasons, and individual preferences, thereby contributing to an extended product lifecycle and reduced consumption.

Existing market practices include garments with detachable elements, multifunctional outerwear, and reversible clothing pieces, all aimed at increasing functionality and prolonging the usability of fashion products. Although these approaches contribute to sustainability goals, they still largely rely on the use of newly produced materials and textiles, which continue to exert pressure on natural resources and the environment.

This research investigates an alternative approach to sustainable modular fashion by shifting the focus from primarily new material production toward the upcycling of textile waste, deadstock fabrics, and discarded garments. By repurposing and transforming these materials into modular and multifunctional design products, the proposed approach simultaneously addresses the challenges of textile waste reduction and resource efficiency. Upcycling not only reduces the amount of waste sent to landfills but also enables the creation of new value from existing materials, thereby lowering the overall environmental footprint of the fashion industry.

The study introduces innovative modular design concepts and manufacturing techniques that highlight the potential of upcycled materials in the development of adaptable, aesthetically relevant, and sustainable products. This approach supports the principles of a circular fashion economy, in which

waste is redefined as a resource, minimalism is encouraged, and responsible consumer behavior is promoted. By integrating modularity with upcycling, the research aims to redefine the future of the fashion industry through the intersection of creative design and environmental responsibility. The proposed model offers a scalable solution for reducing textile waste and demonstrates the potential for sustainable modular fashion to evolve into an industry standard.

## **SIGNIFICANCE OF THE STUDY**

The significance of sustainable modular fashion lies in its capacity to address key environmental, social, and economic challenges within the contemporary fashion industry. This approach plays an important role in reducing the negative impacts of textile waste, which is a major contributor to global pollution and landfill accumulation. The application of upcycling, through the transformation of discarded textiles and unused materials into modular and multifunctional products, enables waste reduction, more efficient use of resources, and a lower environmental footprint of fashion production. From a social perspective, this concept promotes responsible consumption and reduces dependence on fast fashion, while supporting individual expression through adaptable and transformable garments. It also contributes to the development of ethical production practices and creates economic opportunities for small-scale producers, artisans, and local communities. In cultural terms, it encourages creativity and innovation by redefining waste as a resource, while promoting minimalism and sustainability. Additionally, its educational value lies in raising awareness of the environmental impact of the fashion industry and encouraging more sustainable consumption patterns.

The research methodology is based on a structured approach to developing sustainable modular fashion through the application of upcycled textile waste, with the aim of optimizing resource use, minimizing waste, and creating functional design solutions.

The study begins with the analysis of secondary sources to identify key challenges within the fashion industry, including textile waste generation, resource depletion, and emissions. Estimates indicate a very high level of annual textile waste production, while only a minimal proportion of materials is reused in the production of new garments.

Contemporary market trends show a growing demand for sustainable, adaptable, and multifunctional fashion products, particularly among younger consumers. Modular design, based on transformable and interchangeable elements, responds to these needs. However, most existing solutions still rely on newly produced materials, limiting their overall sustainability. In this context, the integration of upcycling into modular design represents a significant direction for development. This approach enables waste reduction while maintaining functional and aesthetic product value. The combination of modularity and upcycling offers a scalable pathway toward circular fashion systems and reduced environmental impact.

## **CONCEPT DEVELOPMENT AND IDEATION**

Every design-driven research process begins with concept generation, and sustainable modular fashion follows this principle. The ideation phase was based on interdisciplinary discussions aimed at addressing key challenges within the fashion industry, including textile waste, overproduction, and limited garment functionality. The primary objective was to explore innovative solutions through the integration of modular design and upcycling strategies.

The study emphasizes the development of multifunctional and adaptable products suitable for diverse contexts. Initial concepts included detachable sleeves, interchangeable collars, and transformable accessories such as hats that can be converted into bags, all designed to enhance versatility and extend product usability.

## **MATERIAL SOURCING: TEXTILE WASTE AND DEADSTOCK**

The material sourcing phase involved the systematic collection of textile waste from multiple sources, including discarded garments, production leftovers, and unsold inventory. These materials were carefully selected based on their durability, quality, and potential for transformation into modular products. The collected resources included post-consumer waste obtained from second-hand markets and donated clothing, as well as post-industrial waste such as fabric off-cuts generated during manufacturing processes. In addition, deadstock materials referring to unused fabrics from manufacturers and retailers were incorporated into the design process. This approach prioritizes the reuse of existing materials and reduces the volume of textile waste that would otherwise end up in landfills.

## **MATERIAL EVALUATION AND CLASSIFICATION**

Following collection, the materials were systematically evaluated and categorized according to their physical and aesthetic properties, including fabric type, texture, condition, and visual characteristics. This classification process ensured that each material was allocated appropriately within the design framework. Natural and synthetic textiles were distinguished to determine their suitability for different applications, while materials in better condition were prioritized for primary garment components. Fabrics with minor imperfections or smaller dimensions were repurposed for secondary elements such as detailing and embellishments. Additionally, visual attributes such as color, pattern, and texture were assessed to enhance the overall aesthetic coherence of modular designs. This stage played a crucial role in maximizing material efficiency and minimizing waste throughout the upcycling process.

- **Design Development and Prototyping**

Design concepts were developed with a focus on functionality, adaptability, and aesthetic coherence. Modular elements such as detachable sleeves, attachable collars, and convertible accessories were refined through sketching and technical planning. Prototypes were created to evaluate usability, attachment mechanisms, and transformation efficiency, ensuring that components are durable, compatible, and user-friendly.

- **Design Inspiration and Visual Direction**

The design approach is informed by the transformation of discarded textiles into innovative modular systems. Emphasis is placed on layered structures, reconstructed materials, and zero-waste principles, supporting circular design practices and sustainable innovation.



*Figure 1: Inspiration example*

- **Color Palette and Aesthetic Strategy**

The selected color palette combines muted earthy tones with soft seasonal contrasts, creating a balance between warmth and freshness. Neutral shades such as beige, taupe, and olive are complemented by accents of ivory, blush, and deeper tones like forest green and rust. This palette enhances versatility, enabling garments to be combined across seasons while reinforcing sustainability and timeless design.



*Figure 2: Inspiration examples color palette*

- **Style Development**

The style direction integrates natural materials, textured fabrics, and modular structures with contemporary design elements. The combination of organic and refined finishes reflects a balance between sustainability and innovation, while modular features support garment transformation and multifunctionality.

- **Trend Analysis**

Trend analysis plays a critical role in aligning design strategies with evolving consumer expectations and industry developments. Current trends indicate increasing demand for sustainable, adaptable, and multifunctional fashion, particularly among environmentally conscious consumers.

Key developments include the adoption of circular design principles, the use of recycled and upcycled materials, and the integration of technology in customization and production processes. These trends support the transition toward slow fashion and resource-efficient systems.

- **Brand Development**

The brand identity is centered on the concept of reuse and transformation, reflecting a shift away from linear consumption models toward circular fashion practices. It emphasizes durability, adaptability, and long-term usability of garments.

- **Pattern Making and Technical Development**

Design concepts were translated into technical patterns, ensuring precision, efficiency, and minimal material waste. Patterns were developed to accommodate modular components, including attachment systems and transformable features.

This stage ensures the integration of functional performance with aesthetic quality.

- **Cutting and Assembly**

Fabric cutting followed optimized layout strategies to reduce material waste. Remaining fabric pieces were repurposed for additional design elements.

Assembly was carried out with attention to durability and usability, particularly in relation to fastening systems such as zippers, buttons, and loops, ensuring repeated functionality of detachable components.

- **Product Development and Testing**

The product development phase focused on refining functionality, durability, and user experience. Prototypes underwent repeated testing to evaluate performance, comfort, and adaptability.

Wear trials were conducted to assess real-life usability, including movement, transformation ease, and long-term durability. Attachment systems were optimized to ensure both stability and flexibility.

Sustainable packaging solutions were also incorporated to align with environmental objectives.

- **Cost Analysis**

Cost evaluation was conducted to determine the economic feasibility of production. This included analysis of material sourcing, labor, production complexity, and additional operational costs.

Although upcycled materials may reduce raw material costs, additional processes such as treatment and reconstruction were considered. Labor costs reflected the level of craftsmanship required for modular construction. Pricing strategies were developed to balance affordability, ethical production standards, and product durability, ensuring market competitiveness.

## CONCLUSION

The methodology for developing sustainable modular fashion demonstrates a structured and integrated approach, encompassing concept development, material sourcing, design innovation, production, and economic evaluation. By utilizing textile waste and deadstock materials, the process promotes sustainability while maintaining functionality and design quality.

The integration of modular design and upcycling contributes to circular fashion systems by reducing waste, extending product lifecycles, and encouraging responsible consumption. This approach provides a scalable and practical framework for advancing sustainability within the fashion industry.

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## **A STRATEGIC ANALYSIS OF DIGITAL TRANSFORMATION AND SOCIO-ECONOMIC CHALLENGES IN THE SERBIAN TEXTILE SECTOR**

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### **Abstract**

This paper analyzes the strategic necessity of digital transformation in the Serbian textile industry, positioning Industry 4.0 as a critical response to ongoing economic stagnation. The research identifies a persistent "structural duality" in the sector: while export performance appears robust, actual value creation remains limited because the industry relies heavily on the low-margin Cut-Make-Trim (CMT) model. The integration of AI, IoT, and Blockchain is examined not merely as a technical upgrade, but as a mandatory defense against the upcoming EU Digital Product Passport (DPP) regulations. Beyond technical implementation, the study proposes a "hybrid operational model" designed to shift firms from passive cost-centers to active value-generators. This transition is identified as essential for generating the revenue required to reach the 800€+ Living Wage benchmark. A significant finding highlights the potential to transfer the "leader mentality" from Serbia's successful IT sector to the textile industry. This cross-sectoral approach is presented as a solution to the "talent paradox," driving the development of new roles such as Digital Supply Chain Architects. Ultimately, the findings provide a roadmap for a "Just Transition," synchronizing large-scale reskilling with domestic leadership to ensure future industrial resilience and strategic autonomy.

**Keywords:** Industry 4.0, Serbian Textile Sector, Digital Product Passport, Leader Mentality, Hybrid Operational Model, Just Transition, Socio-Economic Challenges.

### **1. Introduction**

The global textile and apparel sector is currently experiencing a significant shift driven by the Fourth Industrial Revolution (Industry 4.0). For emerging manufacturing centers like the Republic of Serbia, this change is not merely a choice for improved efficiency but a necessity for maintaining economic viability (Monteiro et al., 2024). Gartner (2025) A key external factor influencing this change is the EU Strategy for Sustainable and Circular Textiles, particularly the rollout of the Digital Product Passport (DPP). Given that Serbia's textile industry is deeply linked to European supply chains, the DPP requirement mandates complete digital traceability of a product's entire lifecycle, from raw material procurement to ethical labor certification (European Commission, 2024). If a robust digital infrastructure is not established, Serbia's local industry risks becoming trapped in outdated, low-value manufacturing practices that increasingly exclude them from the European market.

In the domestic context, this transition is complicated by a notable structural duality. Although sustaining over 55,400 jobs and generating €1.5 billion in exports, the sector remains at risk due to a stagnant percentage of national Gross Value Added (GVA) and an ongoing dependence on low-margin Cut-Make-Trim (CMT) models that limit the industry to the lower tiers of the global value chain (PKS, 2024; RZS, 2024). Moreover, the effective implementation of Industry 4.0 frameworks is obstructed by a "talent paradox," where a substantial workforce lacks the advanced digital skills required for automated environments (Gašić et al., 2025). This paper offers a strategic examination of these challenges, exploring how effective management and technological integration may alleviate

systemic socio-economic issues and support a "Just Transition" towards a high-value, digitally resilient industry.

## **2. Theoretical Framework**

### **2.1 The Convergence of Cyber-Physical Systems and Industrial Management**

The Fourth Industrial Revolution represents more than just a set of disconnected technologies; it embodies the comprehensive integration of Cyber-Physical Systems (CPS) into the core of manufacturing operations. In terms of industrial management, this integration necessitates a shift from conventional hierarchical frameworks to decentralized ecosystems that prioritize data-driven decision-making. The strategic advancement of a "Smart Factory" is evaluated based on the real-time connectivity between the physical production area and the digital management layer. (Gartner, 2025), For the textile industry, this framework is built on a digital "infrastructure" that includes Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) systems. These systems play a crucial role in coordinating production, supported by IoT sensors that deliver a continuous flow of data essential for predictive analytics. The ultimate objective is to realize "Cognitive Manufacturing," where the system is capable of independently detecting fabric imperfections (Monteiro et al. 2024) or signs of equipment wear through AI-enhanced quality assurance models (Ultralytics, 2024).

### **2.2 Managerial Support and the Human-Centric Dimension**

A significant void in industrial management studies, particularly within emerging markets such as Serbia, is the "Implementation Friction" stemming from organizational resistance. Merely having the necessary technical infrastructure does not ensure digital resilience. (Gašić et al. 2025) point out that managerial backing is the most crucial factor determining successful technological adoption among highly educated individuals. In an industry marked by a "talent paradox," managers are challenged to balance the prevailing low-skill workforce with the high-skill demands of automated systems.

In this context, strategic leadership requires Change Management frameworks that focus on psychological safety and transparency. Wiatr (2022) contends that leaders need to shift from "control-based" management to "support-based" leadership to cultivate an innovation-driven environment. Absent this alignment, substantial CAPEX (Capital Expenditure) investments in robotics and AI often do not achieve their intended operational effectiveness due to either underutilization or human errors resulting from cultural resistance.

### **2.3 Standardization and Traceability as Strategic Assets**

For the Serbian textile industry, standardization is no longer merely a compliance task but a strategic asset for EU market integration. The implementation of **ISO 9001 (Quality)**, **ISO 14001 (Environmental)**, and **ISO 45001 (Occupational Health and Safety)** provides the standardized data protocols required for AI and Blockchain integration (European Commission, 2024).

In the era of the **EU Digital Product Passport (DPP)**, the theoretical role of **Blockchain** has shifted from a financial tool to a supply chain "ledger of truth." From an IT management perspective, blockchain provides the immutability required to verify ethical labor standards and material origins. This creates a "Digital Trust Architecture" that allows Serbian manufacturers to prove compliance with global ESG standards, effectively turning ethical production into a quantifiable competitive advantage (European Commission, 2024; Kohan Textile Journal, 2025).

## 2.4. The Smiling Curve and Value Chain Positioning

The strategic positioning of manufacturing industries within global supply chains is conceptualized through the "**Smiling Curve**" model (Shih, 1996). This framework illustrates that value-added is not uniformly distributed across the production lifecycle but is concentrated at the extreme ends of the value chain. The lowest point of the curve represents standardized manufacturing and assembly operations, which are characterized by high competition and low profit margins (Mudambi, 2008). Conversely, the highest value is generated in the pre-production phases—such as Research and Development (R&D) and design—and the post-production phases, including global branding and digital marketing.

In the context of industrial management, the curve highlights a "Value Trap" for developing economies that remain specialized in middle-stage production (OECD, 2024). Moving upward along the curve requires a transition from labor-intensive models to knowledge-intensive ecosystems. Digitalization acts as the primary catalyst for this shift, enabling firms to internalize R&D and design through technologies like 3D modeling and AI-driven consumer analytics. As World Bank (2025) suggests, the ability of a firm to capture a greater share of the Gross Value Added (GVA) is directly proportional to its digital maturity and its capacity to manage intellectual property rather than just physical output.

## 3. Methodology and Strategic Analysis

This research utilizes a qualitative strategic analysis grounded in a deductive reasoning framework to synthesize secondary data through the triangulation of three distinct information streams. The study initially evaluates macro-economic indicators from the Republic Statistical Office and the Chamber of Commerce and Industry of Serbia to establish baseline economic performance and identify the Gross Value Added (GVA) limitations inherent to the domestic textile sector. This economic baseline is subsequently benchmarked against EU regulatory mandates—specifically the Digital Product Passport (DPP) 2027—to determine the strategic gap between current Industry 4.0 adoption rates and upcoming market requirements.

The methodology further incorporates an analogous market analysis, utilizing empirical findings from the Serbian IT sector to assess the feasibility of transferring "leader mentality" traits, such as adaptability and complex problem-solving, into the manufacturing landscape. By applying the Smiling Curve framework as a diagnostic lens, the study systematically evaluates the structural misalignment between production output and value retention. This theoretical synthesis facilitates the development of a model for textile workforce upgrading through the cross-sectoral assimilation of these leadership competencies.

The structural evolution of the Serbian textile industry is at a critical juncture, where the friction between legacy manufacturing models and the imperatives of Industry 4.0 creates a profound strategic gap. The "As-Is" operational state of the sector is defined by a systemic entrapment within the Cut-Make-Trim (CMT) framework. While empirical data from the Republic Statistical Office (RZS, 2024) and the Chamber of Commerce and Industry of Serbia (PKS, 2024) indicate a robust manufacturing base—sustaining 55,400 employees and generating €1.5 billion in exports—the sector's stagnant 0.7% contribution to national GVA reveals a fundamental lack of economic depth. This discrepancy is theoretically anchored in the Smiling Curve (Shih, 1996; Mudambi, 2008), which posits that value creation is polarized at the pre-production (R&D) and post-production (branding) stages, leaving standardized assembly at the curve's nadir.

**Figure 1: Strategic Value Shift on the Smiling Curve**

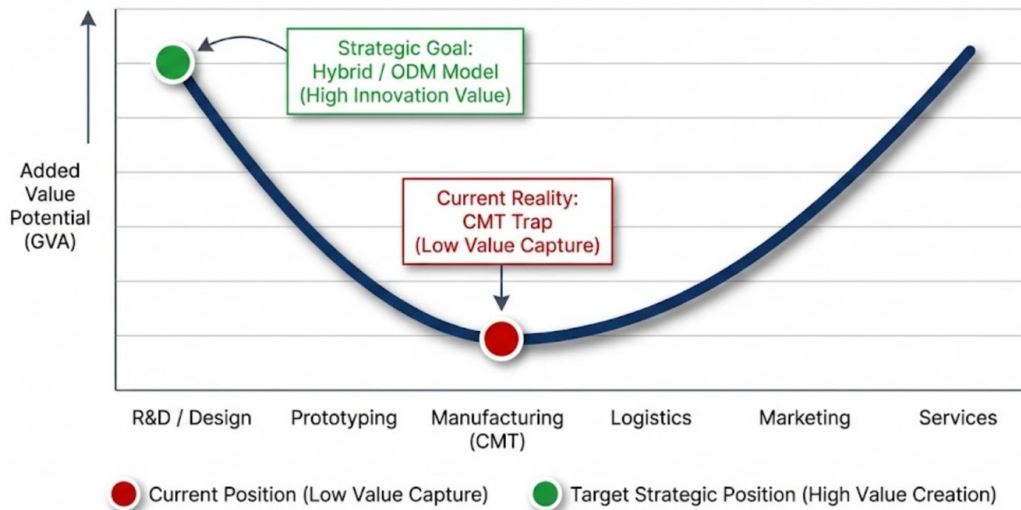


Figure 1 illustrates the sector's current entrapment in low-value CMT manufacturing and the strategic goal of shifting to high-value R&D/Design. This transition relies on a "hybrid operational model" towards ODM to maximize GVA capture.

In this context, "Digital Serfdom" is a strategic condition of data-dependency, where Serbian manufacturers function as externalized production nodes for global lead firms, lacking the sovereignty to utilize proprietary design data or consumer analytics. This creates a socio-economic ceiling where low-margin assembly necessitates suppressed wage structures, that is averaging €407 and significantly below the €800+ Living Wage benchmark (CPE, 2024). Furthermore, the impending EU Digital Product Passport (DPP) mandates represent a strategic threat; without an integrated digital backbone, these enterprises face de-industrialization by obsolescence. The year 2027 stands as a regulatory horizon, where the EU Digital Product Passport mandate will transform digital traceability from a competitive advantage into a baseline requirement for market access (European Commission, 2024).

The transition from dependency to "Digital Emancipation" requires a paradigmatic shift from operational efficiency to strategic autonomy. The bridge between these states is the internalization of R&D and design functions previously held by foreign intermediaries. This shift toward Original Design Manufacturing (ODM) is predicated on the integration of advanced cyber-physical systems. This leap from CMT directly to full-scale ODM may present prohibitive risks for many domestic firms. A more resilient approach is the adoption of a hybrid operational model, where manufacturers maintain their core assembly functions while incrementally 'outsourcing' high-value services such as technical design, prototyping, and digital sampling. This evolutionary path allows firms to build intellectual property assets without abandoning the cash flow provided by traditional contracts. The economic rationale for this shift lies in a radical reconfiguration of the revenue structure. Currently, by providing only CMT services, domestic firms capture only a marginal fraction of total product value, operating as mere cost-centers for global lead firms. However, by internalizing high-value roles through a hybrid model, Serbian enterprises can offer integrated service packages that capture the intellectual capital share previously held by intermediaries. It is this captured economic surplus that will be generated by shifting the firm's position from a low cost-center to a value-generator and a partner, that provides the financial capacity to elevate the base wage toward the 800€+ Living Wage benchmark while ensuring competitive compensation for high-skilled specialists. In this transitional

phase, the digital 'backbone', initially consisting of integrated ERP and 3D design systems, acts as the enabler for these new services. As the firm's digital maturity grows, more advanced architectures such as Artificial Intelligence (AI) for trend forecasting and Blockchain for supply chain transparency can be layered onto this foundation, gradually securing full Strategic Autonomy. This can gradually lead to sustainable and logical shift from predominantly CMT market to more ODM presence.

The successful execution of this internalization is contingent upon the quality of managerial human capital. Building on prior empirical findings on Serbian professional leadership potential (Denčić et al., 2025) provides evidence that the domestic workforce possesses a resilient "leader mentality" and cultural adaptability essential for spearheading high-value industrial projects. While the 'leader mentality' has been empirically documented within the high-growth IT ecosystem (Denčić et al., 2025), this study extends those findings, hypothesizing that these behavioral traits are not sector-exclusive but are latent cultural assets that can be reactivated in the textile industry through targeted managerial interventions. By leveraging these inherent leadership traits to navigate complex cyber-physical architectures, the textile industry can mitigate the "talent paradox" currently hindering its digital maturity.

The final layer of this strategic reconfiguration addresses the socio-technical synchronization inherent in large-scale industrial disruption. The integration of this universal leadership mindset into textile management must facilitate a "Just Transition," ensuring that the 55,400-strong workforce is not displaced but upskilled into roles of system monitoring and data management. This synchronization is the only viable mechanism for breaking the cycle of low productivity. By reclaiming ownership of production data through indigenous leadership, Serbian firms can move upward along the value chain, capturing a greater share of GVA and establishing the economic conditions necessary to elevate industry wages toward the Living Wage standard. Ultimately, this strategic shift ensures compliance with international ESG and digital mandates while transforming the sector from a cost-center for global brands into a sovereign regional hub of innovation.

#### **4. Discussion: Strategic Reconfiguration and the Cognitive Leap Toward Autonomy**

The findings of this research confirm that navigating the Fourth Industrial Revolution in the Serbian textile sector is fundamentally a challenge of strategic repositioning rather than simple automation. The current structural entrapment in low-margin CMT models, as evidenced by the stagnant 0.7% GVA (RZS, 2024), represents a state of "digital serfdom" where domestic firms lack sovereignty over production data and design intellectual property. The discussion suggests that the implementation of Artificial Intelligence (AI), Internet of Things (IoT), and Blockchain must be viewed as the foundational "backbone" for achieving Strategic Autonomy. These technologies enable the internalization of the Research and Development (R&D) segment of the **Smiling Curve (Shih, 1996; Mudambi, 2008)**, allowing Serbian enterprises to comply with the upcoming EU Digital Product Passport (DPP) mandate while reclaiming a higher share of global value added.

While advanced architectures such as Blockchain and Digital Twins represent the technological zenith of digital transformation, the primary strategic objective for the Serbian textile sector leading up to 2027 is the establishment of fundamental digital traceability. Current initiatives focused on the domestic industry emphasize bridging the gap between manual record-keeping and automated data transmission. The primary challenge lies not in the inherent complexity of the technology, but in the strategic readiness of management to standardize processes to meet the minimum requirements of EU regulations (European Commission, 2024).

However, the transition of the Serbian textile sector into the industry 4.0 landscape is equally a challenge of overcoming a profound cognitive inertia regarding the industry's own value-creation potential. This strategic shift is best operationalized through a **hybrid approach**, where firms

maintain their core CMT operations for liquidity while simultaneously integrating high-value intellectual services. By identifying and mapping specific roles and leveraging the strong foundational output from Serbian technical and technological faculties (e.g., Belgrade, Leskovac, Zrenjanin), enterprises can begin to 'outsource' sophisticated leadership and process engineering rather than just manual labor. This hybrid model allows for a gradual and natural expansion, from CMT to ODM, into the R&D segment of the value chain, utilizing the 2026-2027 window to develop roles like Digital Supply Chain Architects, or Technologist as a Process Leader who can manage the technical-technological spectrum of the Digital Product Passport.

**Figure 2: The Evolutionary Path to the Hybrid Operational Model (2025-2027+)**

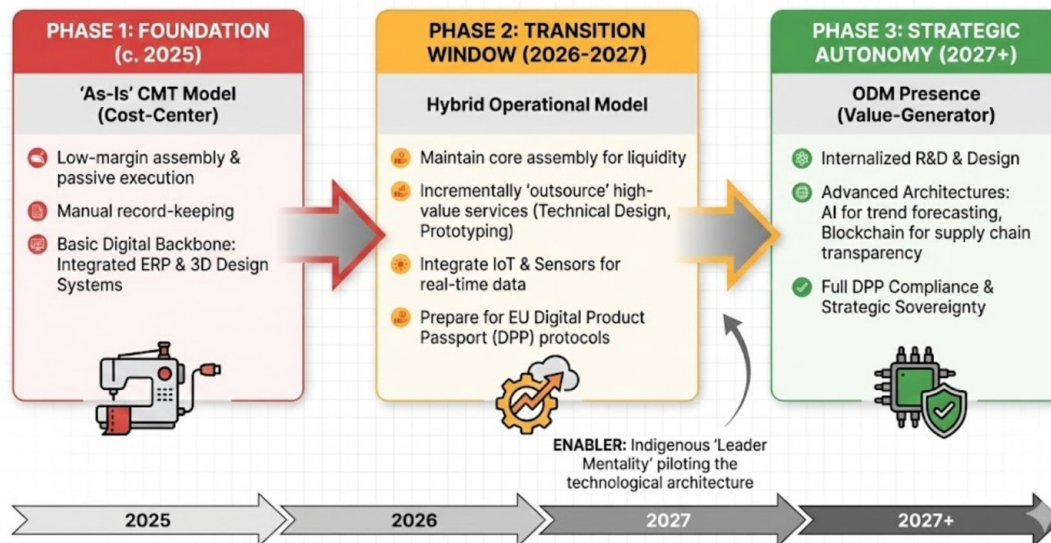


Figure 2 roadmap illustrates the phased transition from the current low-margin CMT model toward a high-value ODM presence. Utilizing the critical 2026-2027 regulatory window, firms must adopt a "hybrid approach," maintaining liquidity through assembly while integrating high-value intellectual services.

While this study identifies the necessity of this role-mapping, a detailed interdisciplinary analysis of these new professional competencies remains a vital area for future research.

The "talent paradox" identified in manufacturing (Gašić et al., 2025) is not merely a deficit of technical competencies, but a manifestation of perceptual misalignment. For decades, the domestic workforce has been socialized into a role of passive execution, leading to a pervasive unawareness of their own capacity to manage complex systems. This lack of awareness, often coupled with a fear of technological displacement and a perceived lack of soft skills, acts as a significant barrier to industrial evolution. This research posits that digital transformation serves as the necessary "cognitive alarm", a catalyst that shifts the labor base from a mindset of manual repetition to one of data-driven agency, where workers recognize that their true value lies in the management of the digital "backbone" rather than physical labor alone.

A critical synthesis of this study is the identification of the "**leader mentality**" as the vital pilot for this technological architecture. As evidenced in the high-growth IT sector (Denčić et al., 2025), the Serbian professional landscape possesses a latent capacity for leadership characterized by high adaptability, cultural resilience, and strategic problem-solving. This study posits that such

professional attributes could serve as a cross-sectoral asset of the Serbian professional elite, capable of being operationalized in manufacturing to achieve digital emancipation. Integrating this leadership potential is the primary mechanism for mitigating the fear of change; it provides the strategic vision necessary to transform the 55,400-strong workforce into system operators who can navigate complex cyber-physical architectures.

Furthermore, achieving Strategic Autonomy is inextricably linked to the socio-economic welfare of the national economy. The 'value trap' of the current model sustains a suppressed wage structure (avg. 407€) that is fundamentally incompatible with the Living Wage benchmark of 800€+ (CPE, 2024). This study suggests that only through the digital emancipation of the sector—facilitated by indigenous leadership and the adoption of a hybrid operational model—can the industry generate the economic surplus required to elevate labor standards. By strategically integrating high-value roles and utilizing the 2026-2027 window to transition toward intellectual service outsourcing, the sector creates a sustainable foundation for the eventual emergence of Original Design Manufacturing (ODM). In this trajectory, the hybrid approach acts as a catalyst, allowing Serbian firms to mature from passive contractors into sovereign regional hubs of innovation. This shift requires a 'Just Transition' framework where technology is utilized to augment human capital rather than replace it (Wiatr, 2022). Ultimately, the synchronization of the domestic 'leader mentality' with the legacy of textile manufacturing provides a strategic roadmap for bridging the gap between historical dependency and future industrial resilience.

## 5. Conclusion

The Serbian textile sector is no longer able to choose its digital future, as it is facing a regulatory ultimatum. The EU Digital Product Passport 2027 is the hard deadline that will separate the resilient from the obsolete. This research confirms that the current state of "digital serfdom" under the CMT model is a possible strategic dead-end. To break this cycle, the industry must stop competing on cheap labor and start adding organized intellectual capital to the competition.

The transition to Strategic Autonomy is not uninformed leap into automation, but a calculated **hybrid shift**. By utilizing the 2026-2027 window to map high-value roles and leverage the untapped potential of domestic technical faculties, Serbian firms can transform from passive contractors into sophisticated partners. While technology provides the infrastructure, the leader mentality acts as a critical catalyst for a fundamental shift in revenue structure. By internalizing high-value roles, firms can transition from selling low-margin labor to providing integrated service packages that capture a significantly larger share of the product's total market value.

It is this captured economic surplus by shifting the firm's position from a cost-center to a value-generator that provides the financial capacity to elevate the base wage toward the **800€+ Living Wage benchmark** while ensuring competitive compensation for high-skilled specialists. Without this radical reconfiguration, the framework for a "**Just Transition**" will remain a theoretical ideal rather than a reality. Serbia will inevitably remain anchored as an undigitalized, low-cost center with substandard labor conditions, failing to bridge the gap between historical dependency and future industrial resilience. The roadmap is clear: synchronize organized intellectual capital with the digital backbone or accept permanent economic marginalization.

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## AIR PERMEABILITY OF RIGHT-LEFT SMOOTH COTTON KNITS DEPENDING ON THE NUMBER OF KNIT LAYERS AND AIR PRESSURE

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### ABSTRACT

*Air permeability of cotton knitted fabrics is a key parameter that determines the thermophysiological properties and functionality of the finished product. This study analyzes the influence of the number of fabric layers and air pressure on the air permeability of plain knitted cotton fabrics (100% cotton). Tests were conducted in accordance with the SRPS EN ISO 9237:2010 standard at air pressures of 50 Pa, 100 Pa, 200 Pa, 300 Pa, and 400 Pa, with each material tested with one, two, three, and four layers, simulating different construction variants, from single-layer structures for everyday use to multi-layer structures for specific applications. The results show that the number of layers has a dominant influence on air permeability. For single-layer materials, permeability ranged from 39.3 to 68.05 cm<sup>3</sup>·cm<sup>-2</sup>·s<sup>-1</sup> at a pressure of 200 Pa, ensuring more efficient airflow and better thermoregulation. In double-layer structures, permeability decreased by 55-60%, while in multi-layer structures (with four layers), the reduction reached a range of 75-85%. It was also observed that permeability increases with increasing pressure, which is relevant for different applications. The research results provide important guidelines for designing textile products with optimal thermophysiological properties, enabling manufacturers to select appropriate materials and constructions depending on functional purpose, seasonal application, and specific requirements for better thermophysiological properties and thermal protection.*

**Keywords:** plain knitted fabric, number of layers, air pressure, air permeability

### INTRODUCTION

Knitted fabrics are textile materials characterized by a specific structure, and unlike woven fabrics in which yarns are interlaced at right angles, knitted fabrics are characterized by a continuous and flexible structure that provides them with a high degree of elasticity, extensibility, and the ability to adapt to body shape [1]. These properties make knitted fabrics suitable for wide application in the production of clothing, sportswear and technical textiles, medical materials, as well as protective and functional materials. Plain knitted fabrics, as the most commonly used single weft knitted structures, are characterized by the appearance of knit stitches on the face side and purl stitches on the reverse side of the material, giving them specific properties in terms of elasticity, dimensional stability, and air permeability [2].

Air permeability is one of the most important factors determining the comfort and functionality of knitted fabrics. This parameter defines the material's ability to allow airflow through its structure and directly affects thermal comfort, moisture regulation, and wearing sensation [3]. High air permeability is desirable in sportswear and summer clothing, while lower permeability can contribute to better thermal insulation in winter materials [4]. Air permeability through knitted fabrics depends on several factors: construction, stitch density, thickness, number of layers, raw material composition, elasticity, and porosity [5]. Each of these factors affects the size and distribution of micropores through which air passes, and consequently the overall functionality of the material. Numerous studies have shown that the structure of knitted fabric, number of layers, and air pressure significantly affect permeability [6].

Air permeability  $P_v$  (or porosity) represents the amount of air passing through a material of a certain area and for a certain time, at a defined air pressure  $p$  (Pa):

$$P_v = \frac{V}{A \cdot t} \quad (1)$$

where:  $P_v$  - air permeability through textile material ( $\text{cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ , or  $\text{cm} \cdot \text{s}^{-1}$ ),  $V$  - amount or volume of air passed ( $\text{cm}^3$ ),  $A$  - fabric area, i.e., working area of the sample ( $\text{cm}^2$ ),  $t$  - air passing time (s).  
 The aim of this research is to analyze the air permeability through plain knitted cotton fabrics depending on the number of material layers and air pressure. The research results can contribute to the study of knitted fabric behavior during use and optimization of their application in different types of textile products.

## MATERIALS AND METHODS

Four plain knitted weft knitted fabrics made of 100% cotton were used in the research, whose technical characteristics are given in Table 1.

Table 1. Technical characteristics of knitted fabrics

Knitted fabric	Linear yarn density, $T_l$ (tex)	Horizontal density, $D_h$ ( $\text{cm}^{-1}$ )	Vertical density, $D_v$ ( $\text{cm}^{-1}$ )	Fabric weight, $Q$ ( $\text{g} \cdot \text{m}^{-2}$ )
1	20	16	20	190
2	22	16	20	160
3	22	16	20	170
4	20	14	20	220

Eksperimenti su sprovedeni u skladu sa odgovarajućim standardima:

Experiments were conducted in accordance with relevant standards:

- Knitted fabric samples were standardly conditioned and prepared for laboratory testing according to SRPS EN ISO 139:2007/A1:2014.
- Linear yarn density was determined according to SRPS EN 14970:2014 standard.
- Knitted fabric density was determined according to SRPS EN 14971:2012 standard. Measurements were performed at five different locations for each sample.
- Fabric weight was determined according to SRPS EN 12127:2014 standard.
- Knitted fabric thickness was determined according to SRPS EN ISO 5084:2013 standard. Measurements were conducted for one, two, three, and four layers, with ten measurements for each configuration.
- Other characteristics of knitted fabrics were determined according to generally known formulas that connect the interdependence of their characteristics.
- Air permeability was determined according to SRPS EN ISO 9237:2010 standard. Measurements were conducted at five different pressures (50 Pa, 100 Pa, 200 Pa, 300 Pa, and 400 Pa) for one, two, three, and four layers of material.

## RESULTS AND DISCUSSION

The results of testing the most significant characteristics of knitted fabrics that affect air permeability are shown in Table 2.

Table 2. Results of testing knitted fabric characteristics

Knitted fabric	Linear yarn density, $T_l$ (tex)	Horizontal density, $D_h$ ( $\text{cm}^{-1}$ )	Vertical density, $D_v$ ( $\text{cm}^{-1}$ )	Fabric weight, $Q$ ( $\text{g} \cdot \text{m}^{-2}$ )	Stitch length, $l$ (mm)	Knitted fabric thickness, $h_{pl}$ (mm)	Volume density, $\gamma_{pl}$ (mm)
1	20,1	14,7	22	193	2,97	0,54	0,357
2	22,1	16	20,2	161	2,25	0,466	0,345

3	22	16,2	20,2	169	2,35	0,472	0,358
4	20,4	14,2	20,6	225	3,77	0,565	0,398

The most significant differences between samples were observed in fabric weight (or can also be stated as the total amount of yarn per unit area), which ranged from 161 g·m<sup>-2</sup> (knitted fabric 2) to 225 g·m<sup>-2</sup> (knitted fabric 4), representing a difference of approximately 40%. This difference is directly related to linear yarn density, fabric density, and stitch length.

Figure 1 (as well as in Tables 3-6) shows the thickness values of knitted fabrics depending on the number of fabric layers. These values are significant due to their direct influence on air permeability through knitted fabrics.

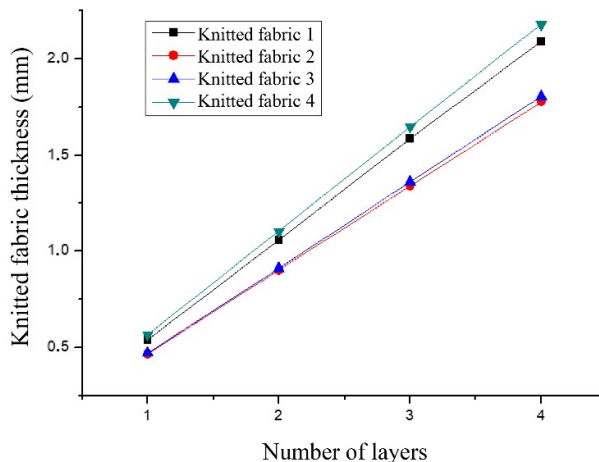


Figure 1. Change in knitted fabric thickness, i.e., structure depending on the number of layers

The material thickness shows an approximately linear increase with increasing number of layers for all tested knitted fabric samples. For knitted fabric 1, thickness increased from 0.54 mm (one layer) to 2.091 mm (four layers), representing slightly less than a fourfold increase (due to material compressibility between thickness gauge plates). Similar proportions were maintained for the other three knitted fabrics (Table 2), indicating uniform increase in material thickness when layering.

The results of testing air permeability through knitted fabrics depending on material thickness, i.e., number of layers, at different air pressures, are shown in Tables 3-6.

Table 3. Air permeability results for knitted fabric 1

Knitted fabric 1	Layer thickness, $h_{pl}$ (mm)	Air pressure, $p$ (Pa)				
		50	100	200	300	400
1 layer	0.54	10.63	21.96	45.46	86.63	124.5
2 layers	1.058	5.6	10.78	19.31	35.41	47.74
3 layers	1.584	3.7	7.53	13.87	20.65	30.34
4 layers	2.091	2.7	5.33	10.54	16.3	21.32

Table 4. Air permeability results for knitted fabric 2

Knitted fabric 2	Layer thickness, $h_{pl}$ (mm)	Air pressure, $p$ (Pa)				
		50	100	200	300	400
1 layer	0.466	16.14	31.16	68.05	135	188.5
2 layers	0.902	6.99	14.08	31.81	49.83	68.08
3 layers	1.338	4.84	9.75	19.65	33.67	43.74
4 layers	1.776	3.46	7.21	13.54	21.24	31.63

Table 5. Air permeability results for knitted fabric 3

Knitted fabric 3	Layer thickness, $h_{pl}$ (mm)	Air pressure, $p$ (Pa)				
		50	100	200	300	400
1 layer	0.472	13.83	24.67	54.64	96.84	161
2 layers	0.911	6.4	11.44	23.46	37.35	53.09
3 layers	1.36	4.18	7.56	15.45	24.34	32.6

4 layers	1.806	2.56	5.49	11.6	17.56	23.59
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Table 6. Air permeability results for knitted fabric 4

Knitted fabric 4	Layer thickness. $h_{pi}$ (mm)	Air pressure. $p$ (Pa)				
		50	100	200	300	400
1 layer	0.565	9.52	18.76	39.3	60.66	103.6
2 layers	1.103	4.84	9.58	17.73	28.85	41.33
3 layers	1.646	3.11	6.31	11.81	18.04	25.17
4 layers	2.181	2.26	4.78	9.48	13.74	18.05

It was observed that with increasing number of layers, there is a significant decrease in air permeability for all tested materials and for all air pressures. For example, for knitted fabric 1 at a pressure of 200 Pa, permeability decreased from  $45.46 \text{ cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$  (one layer) to  $10.54 \text{ cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$  (four layers), representing a reduction of approximately 77%. Similar behavior was observed for other samples, with the percentage reduction ranging from 75% to 85%, depending on the knitted fabric sample and air pressure. It was also observed that air permeability increases with increasing air pressure for all knitted fabric samples. For example, for knitted fabric 1 with one layer, permeability increased from  $10.63 \text{ cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$  at 50 Pa to  $124.5 \text{ cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$  at 400 Pa.

Figures 2 and 3 show the change in air permeability through knitted fabrics 1, 2, 3, and 4 depending on layer thickness for different air pressures.

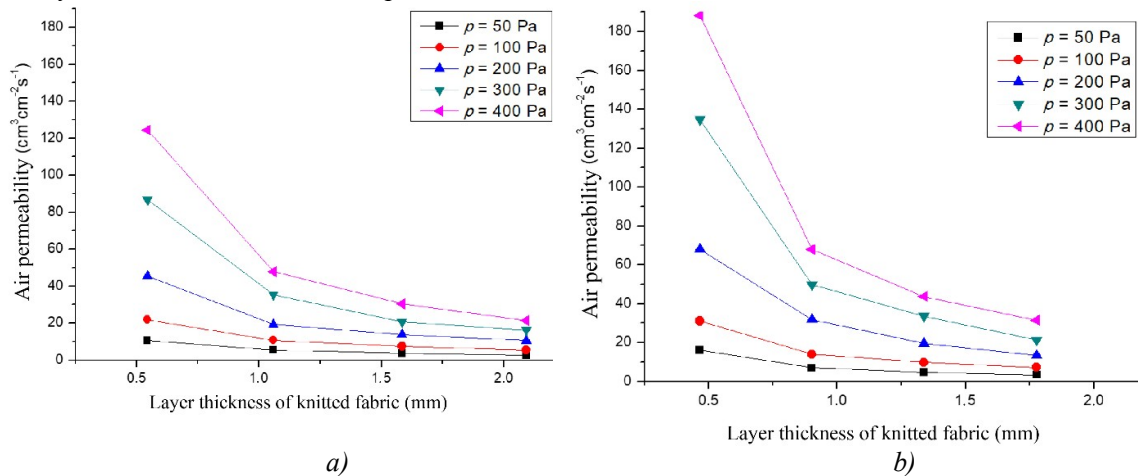


Figure 2. Change in air permeability through knitted fabrics depending on layer thickness for different air pressures

a) knitted fabric 1; b) knitted fabric 2

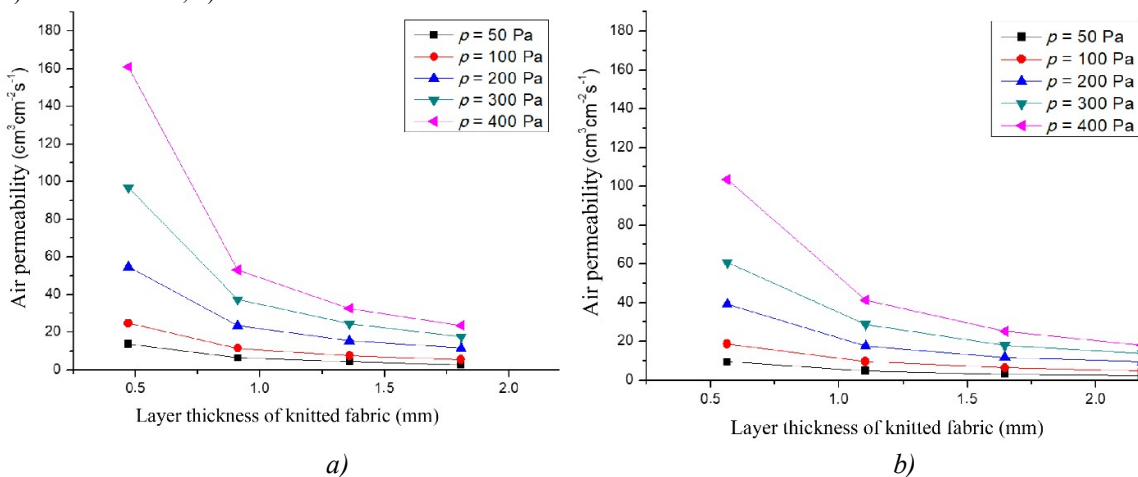


Figure 3. Change in air permeability through knitted fabrics depending on layer thickness for different air pressures

a) knitted fabric 3; b) knitted fabric 4

It was observed that air permeability decreases nonlinearly with increasing material thickness (i.e., number of knitted fabric layers), with the most intensive drop in the range from 0.5 mm to 1 mm thickness, after which the curves show a stagnation tendency. The second observation is that permeability increases with increasing pressure, which can be seen from the vertical markings on the graphs.

Knitted fabric 2 shows significantly higher permeability values compared to knitted fabric 1 at all material thicknesses and air pressures. For example, at a pressure of 400 Pa and thickness of 0.5 mm, knitted fabric 2 has an air permeability of  $188.5 \text{ cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ , while knitted fabric 1 has an air permeability of  $124.5 \text{ cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ . This difference is directly related to the lower fabric weight of knitted fabric 2 and lower thickness of individual layers compared to knitted fabric 1.

Differences between air permeability become more pronounced at smaller knitted fabric thicknesses, i.e., number of layers, while at greater thicknesses ( $>1.5 \text{ mm}$ ) the differences are smaller and tend toward low permeability values (below  $30 \text{ cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ ). This fact indicates that in multi-layer knitted fabric construction, total thickness becomes the dominant factor and the influence of air pressure is significantly reduced.

For knitted fabrics 3 and 4, the trend of nonlinear decrease in air permeability with increasing thickness continues. However, significant quantitative differences between them are observed. At a pressure of 400 Pa and thickness of 0.5 mm, knitted fabric 3 reaches an air permeability of  $161 \text{ cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ , while knitted fabric 4 achieves only  $103.6 \text{ cm}^3 \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$ . Samples of knitted fabric 4, with the highest fabric weight ( $225.5 \text{ g} \cdot \text{m}^{-2}$ ) and thickness (0.565 mm) of all tested materials, show the lowest air permeability values at all pressures and layer thicknesses. This makes it most suitable for applications where structural stability and thermal insulation are priorities.

The decrease in air permeability through knitted fabrics depending on layer thickness can be explained by the lengthening of the airflow path and increased material resistance due to pore overlap between material layers.

Figures 4 and 5 show the change in air permeability through knitted fabrics 1, 2, 3, and 4 depending on air pressure for different numbers of layers.

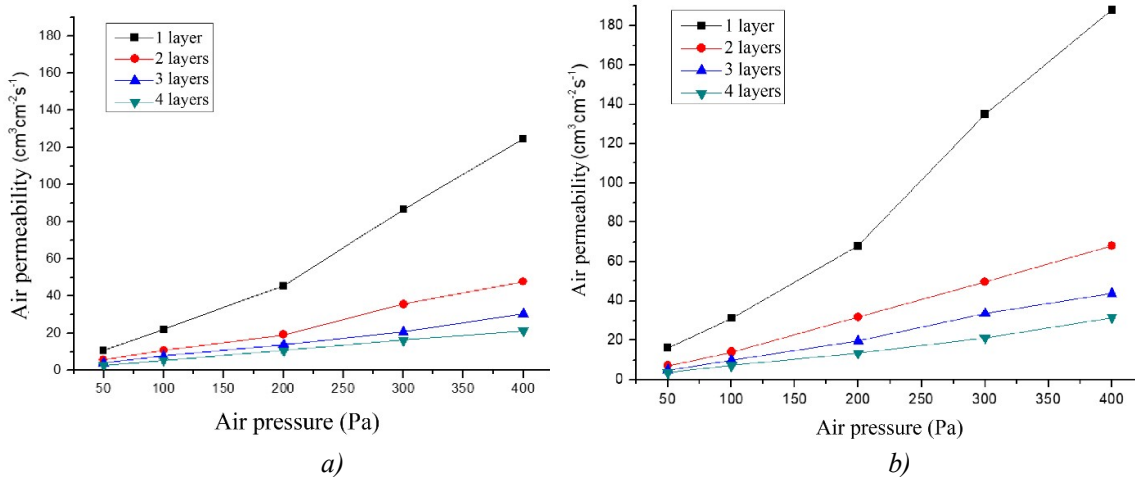


Figure 4. Change in air permeability through knitted fabrics depending on air pressure for different numbers of layers a) knitted fabric 1; b) knitted fabric 2

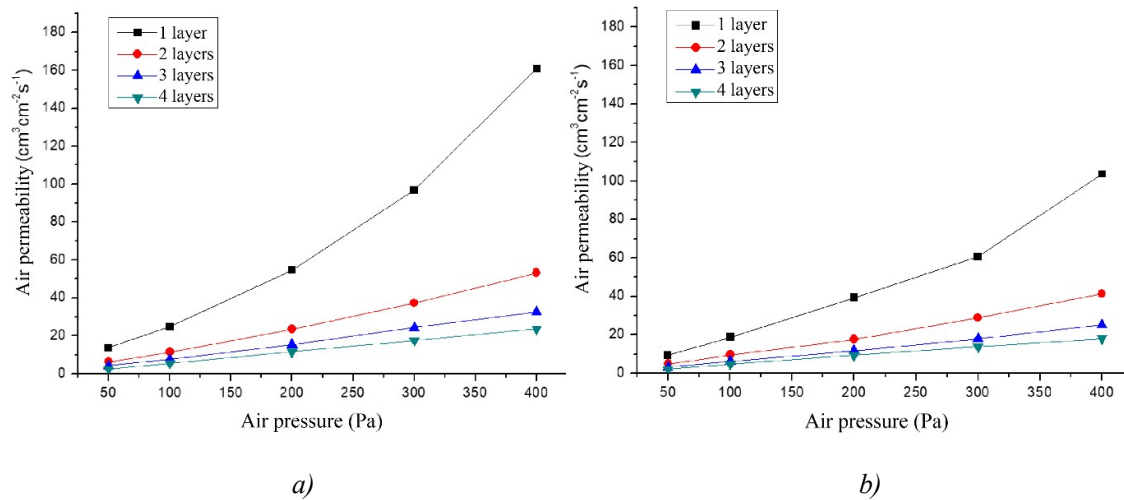


Figure 5. Change in air permeability through knitted fabrics depending on air pressure for different numbers of layers a) knitted fabric 3; b) knitted fabric 4

Increasing pressure from 50 Pa to 400 Pa leads to an increase in air permeability through knitted fabrics, which is understandable. At 50 Pa, values range from 9.52 to 16.14 cm<sup>3</sup>·cm<sup>-2</sup>·s<sup>-1</sup> (one layer), while at 400 Pa they reach 103.6 to 188.5 cm<sup>3</sup>·cm<sup>-2</sup>·s<sup>-1</sup>. For single-layer knitted fabric samples, there is a nonlinear change in air permeability, while for others the change is almost linear, which can be attributed to material compressibility and pore closure.

Interestingly, the degree of reduction in air permeability was different for different samples. Knitted fabric 4, which has the highest fabric weight and thickness, showed the greatest relative reduction in permeability when adding layers (about 85% reduction for four layers compared to one layer at 200 Pa), while knitted fabric 2, with the lowest fabric weight, showed a somewhat smaller reduction (about 80%). This indicates that in addition to the number of layers, the structural characteristics of the material itself play an important role in determining the effects of layering on permeability [5].

Differences between knitted fabric samples in terms of air permeability are more pronounced at smaller thicknesses, while at greater thicknesses all curves are directed toward smaller differences in values. This suggests that in multi-layer constructions, total thickness has a dominant influence, while structural differences of individual knitted fabrics become less significant.

These results are consistent with previous research confirming that multi-layer textile systems are characterized by increased thermal resistance and reduced airflow, which is of essential importance when designing clothing that should provide thermal comfort and optimal ventilation [3, 5, 11].

For winter or protective clothing, where better thermal insulation with limited air permeability is needed, multi-layer structures or materials with higher fabric weight (similar to knitted fabric 4) may be more suitable. A combination of two or three layers of such materials can provide an optimal balance between thermal insulation, mechanical protection, and acceptable ventilation levels [11].

It is particularly important to note that air pressure in real clothing wearing conditions can vary significantly depending on air movement speed around the body (wind) or user activity. Pressures of 50-100 Pa correspond to calm air conditions or light activity, while pressures of 200-400 Pa may correspond to strong wind conditions or intensive physical activity. Therefore, when designing functional textile products, it is necessary to take into account expected usage conditions to achieve optimal permeability for a given application.

## CONCLUSION

This research provided a detailed analysis of air permeability through plain knitted cotton fabrics depending on the number of layers and air pressure. The main conclusions are as follows:

With increasing number of layers, there is a significant decrease in air permeability for all tested

materials, with the air permeability of four fabric layers decreasing by 75-85% compared to one layer. The reduction is not linear but shows a decreasing tendency with each additional layer.

Increasing air pressure leads to increased airflow through the material, with the relationship between these two parameters showing deviation from linearity at higher pressures due to knitted fabric compression and possible turbulent effects. This presentation enables direct assessment of material behavior in different operating conditions—from static wearing (50-100 Pa) to dynamic conditions with increased air circulation (300-400 Pa), which is of practical importance for optimizing material and construction selection depending on purpose and seasonal conditions.

Fabric weight and material thickness are key parameters that determine air permeability. Knitted fabric samples with lower fabric weight showed significantly higher permeability compared to samples with higher fabric weight.

The results of this research provide important guidelines for optimizing textile product design according to desired thermophysiological properties. For sportswear and summer clothing, the use of single knitted fabrics with lower fabric weight is recommended, while for winter or protective clothing, multi-layer structures or materials with higher fabric weight are more suitable. Further research should be directed toward analyzing the influence of different stitch types, fiber blends, and finishing treatments on air permeability, as well as developing mathematical models that would enable prediction of permeability based on structural parameters of materials.

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# THE IMPACT OF THE TECHNOLOGICAL PROCESS OF MAKING A DOUBLE WELT POCKET ON THE OPTIMIZATION OF PRODUCTION TIME

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## SUMMARY

*This paper covers data obtained from measuring sewing speed, in order to analyze the applied knowledge and skills and directly compare two methods of making the same final product.*

*The goal of this paper is to find a faster and easier way to make a double welt pocket by analyzing the production time and choosing a simpler process. In the textile industry, optimizing production time is important, so that by reducing work steps and shortening the production time, you get a high quality final product.*

**Keywords:** double welt pocket, production time, technological process, textile industry, product quality

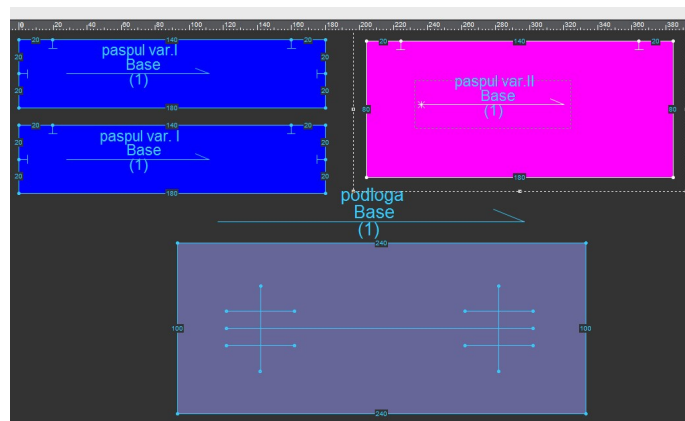
## 1. INTRODUCTION

The quality of production is a key factor and requires well organized and technologically set up production. Strictly defined conditions and level of quality requires appropriate technological preparation. Product quality directly determines the speed and the method of production. A theoretical approach to the technological setup of production requires practical examples of manufacturing methods in order to prevent serial errors and maintain product quality, and thereby speed up the production cycle. (Nikolić G. 2000)

The textile industry aims to optimize production time, modernize processes, reduce costs, and deliver high quality finished products. Highly specialized workshops that produce only specific programs and types of models invest in specialized sewing machines, automated equipment, and devices. However, a large number of workshops still perform most of their operations on traditional lockstitch sewing machines.

The subject of the research is a a double welt pocket, without decorative topstitching; the welt width is 0.5 cm and the length is 14 cm. The study will examine the time required to open and form the pocket up to the operation of attaching the pocket bag.

A comparison was made between two technological methods for making a double welt pocket. In preparation for Method I, two piping swelts are cut, each 4 cm wide and 18 cm long, while for Method II, a single cut piece 8 cm wide and 18 cm long is prepared, from which both welts are made. The aim of this study is to determine the more efficient method for making a double welt pocket by analyzing the production time.



*Figure 1. Preparation of patterns for two variants of double welt pocket*

## 2. TECHNOLOGICAL PROCEDURE FOR MAKING A DOUBLE WELT POCKET

Technological analysis of garment production involves a detailed breakdown of the technological process into a rational number of procedures, operations, actions, movements, and micro movements. It also includes the selection of the most suitable machines and equipment. Industrial garment production involves dividing the work into multiple technological operations. For industrial production of simpler garments, around ten technological operations are usually sufficient, while the production of more complex garments may require several hundred operations. The technological procedure for making a double welt pocket represents just one of a series of operations in the production of trousers, vests, blazers, jackets and other garments that feature welt pockets.

The result of technological analysis is a set of necessary technological operations for the production of a garment. The operations, as well as their number, must be rational and adapted to the level of technical equipment of the available work resources. Technological analysis is also used to determine and select the most suitable working methods, machines, and devices on which these methods will be applied. Considering that in garment technology many technological operations can be performed using different methods and various machines and devices, the technological analysis of production should select the optimal method that ensures high productivity with minimal production time and energy consumption. (Rogale D., Ujević D., Firšt Rogale S., Hrastinski M., 2011.)

### 2.1. Method I

The stages of making a double welt pocket using Method I are:

- Marking the pocket position (Determine pocket position and mark a length of 14cm, draw reference lines 1 cm above and below the center of the pocket.) (RR)
- Pressing the two welts on half (Fold the welt stripes, align the edges and press.) (PP)
- Sewing the first welt (Place the lower welt strip along the bottom edge and stitch 0.5 cm from the edge.) (OM)
- Sewing the second welt (Place the second welt strip along the top edge so that the lines align, and stitch 0.5 cm from the edge. The pressed straight lines should face opposite directions. The seams must be parallel and of equal length.) (OM)
- Cutting the pocket (From the wrong side of the fabric, cut between the two topstitch lines, but not along the entire length. The pocket opening starts and ends up to 1.5 cm from the seams. From the end of the cut, carefully cut toward the seam ends, forming small triangles. Do not cut all the way to the corner; leave one or two threads.) (RR)
- Turning the pocket (Through the opening of the cut seam, turn the welt strips right side out from corner to corner using your fingers. (RR)
- Securing the triangles (OM)

The stages of making a double welt pocket using Method I are shown in Figure 2. The work tools used in Method I are: manual work (RR), ordinary sewing machine (OM), and steam iron (PP).

### 2.2. Method II

The stages of making a double welt pocket using Method II are:

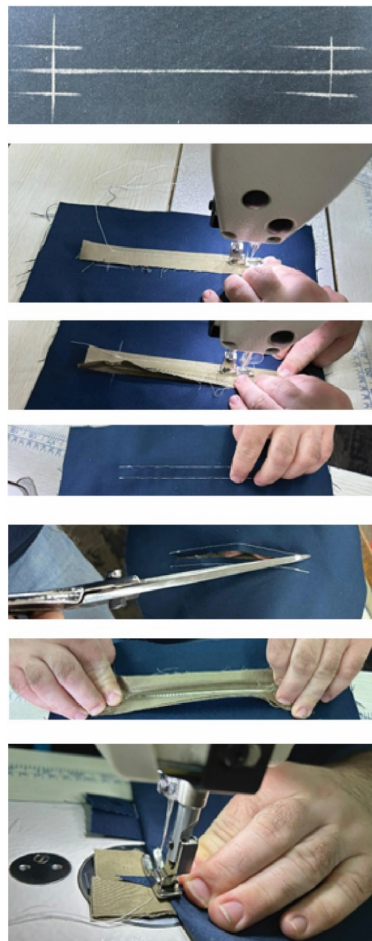
- Marking the pocket position (RR)
- Forming the first welt on one side and sewing it onto the base 0.5cm from the edge (OM)
- Forming the second welt on the other side and sewing it onto the base 0.5cm from the edge (OM)

- Cutting the pocket (RR)
- Turning the pocket (RR)
- Securing the triangles (OM)

When making a double welt pocket using the second method, where both welts are made from a single cut piece, the number of operations is reduced and the production process is simplified. This method does not require intermediate pressing, allowing the sewer to form the welts more quickly and handle the workpiece more easily. The stages of making a double welt pocket using Method II are shown on Figure 3. The work tools used in Method II are: manual work (RR) and ordinary sewing machine (OM).

### 3. EXPERIMENTAL PART

The research was performed at the School of textile design, Belgrade. The subject of the study is the production of a double welt pocket using two methods. Ten measurements were taken for each method. The sewer worked under the same conditions throughout the entire study and experienced similar levels of fatigue.

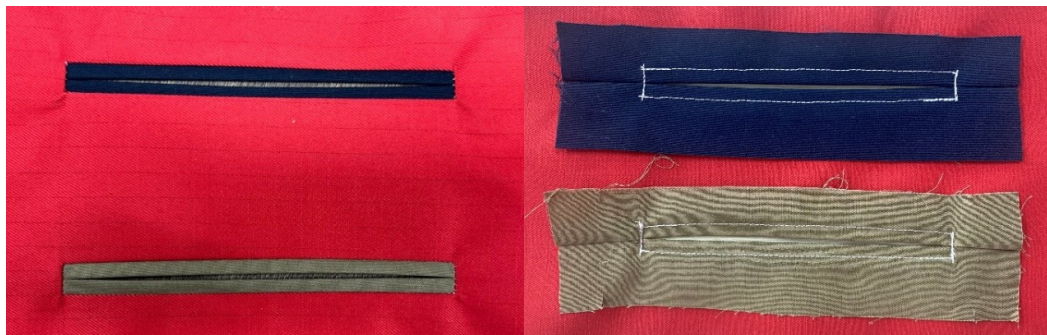


*Figure 2. Method I of making a double welt pocket through phases*



*Figure 3. Method II of making a double welt pocket through phases*

By making a double welt pocket using both methods, the same final product is obtained, with its appearance shown from face and back of the fabric in Figure 4.



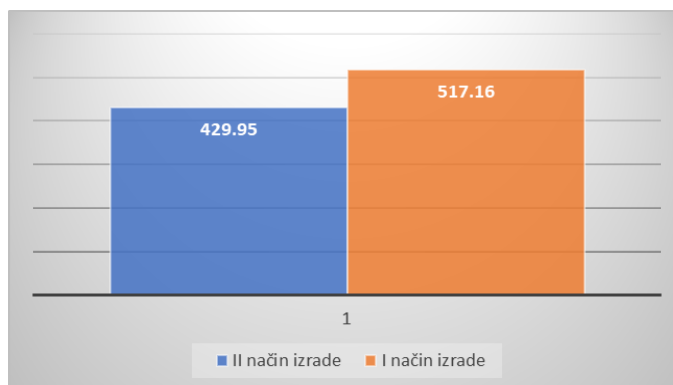
*Figure 4. Final appearance of the double welt pocket made by both methods, from the face and back of the fabric*

Table 1 shows the results of measuring the production time of a double welt pocket using Methods I and II. The shortest production times are highlighted in green, while the longest times are highlighted in red. Analysis of the results shows a time difference of 87.21 seconds between Methods I and II.

The chart shown in Figure 5 indicates that the production time is shorter for Method II of making a double welt pocket, and that this method is the more optimal choice.

*Tabel 1. Production time measurements in seconds*

Production time measurements	Method I	Method II
1.	437.11	514.25
2.	451.00	409.31
3.	440.71	476.23
4.	496.28	388.08
5.	560.49	436.74
6.	525.04	412.12
7.	549.96	394.00
8.	686.68	406.95
9.	508.35	496.15
10.	516.00	365.62
Avarage (s)	517.16	429.95



*Figure 5. Comparison of production time of double welt pocket using two mwthods*

#### **4. CONCLUSION**

Many technological operations can be performed using different methods and various work resources. It is necessary, through technological analysis of production, to select the optimal method that ensures high productivity, preserves product quality, and minimizes both production time and energy consumption.

Analysis of the two technological methods for making a double welt pocket showed that Method II requires 1 minute and 27.21 seconds shorter than Method I. When planning production and the technological procedure, the method with fewer operations, faster execution, and easier handling should be adopted, while delivering the desired final product with satisfactory appearance and appropriate quality.

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## **PATTERNING AND SURFACE DESIGN OF MYCELIUM MATERIALS FOR CREATIVE INDUSTRIES**

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### **ABSTRACT**

*Mycelium-based materials, cultivated from fungal mycelium on organic or waste substrates, are emerging as promising bio-composites in the fields of textiles and design. Their lightweight structure, biodegradability, and moldability make them suitable not only for functional applications but also for aesthetic exploration. This paper focuses on experimental methods to enhance the visual and tactile qualities of mycelium composites. It includes a detailed review of international precedents on patterning and surface design with mycelium-based materials, as well as the presentation of our own experimental trials in pattern formation. By combining precedent analysis with practice-based experiments, the study demonstrates how aesthetic interventions - such as moulding, engraving, and surface texturing - can expand the creative and design potential of mycelium composites, positioning them as viable and inspiring alternatives for sustainable material innovation in the textile and design industries.*

**Key words:** : biodesign 1, mycelium materials 2, surface design 3, waste recycling 4

### **INTRODUCTION**

We are living in the era of climate and ecological crisis, which poses unprecedented challenges to both our planet and humanity. Biodesign seeks to respond to these challenges by offering innovative approaches that transcend the boundaries of science, nature, technology, and the arts. One of its most significant achievements is the redefinition of material production through the cultivation of living, biological substances. To grow such materials, designers and researchers employ fungi, bacteria, or plants as active agents in the process. (Karana E. 2018, Farias G. 2024)

This paper focuses on materials created with the help of fungal mycelium networks, known as mycelium-based materials. Our aim is to explore how these materials can be made more acceptable and aesthetically appealing for people and end-users, moving beyond their functional qualities toward new cultural and design values.

### **DEFINITION OF MYCELIUM-BASED MATERIALS**

Mycelium is the vegetative part of fungi. From a material production perspective, its most important characteristic is that it consists of root-like filaments, known as hyphae, which are capable of growing through a substrate. (Karana E. 2018, Farias G. 2024) The type of substrate varies depending on the fungal species; in the case of those used for material cultivation, it is typically lignocellulosic. Common substrates include straw, hay, sawdust, other plant fibers, and cellulose-based textile waste. (Farias G. 2024, Márföldi 2021)

Depending on whether the material is used together with the substrate or separated from it, we can distinguish between pure mycelium materials and mycelium-based composites. In composites, the mycelium acts as a binder, serving as the matrix. Pure mycelium materials are generally leather- or foam-like, making them suitable for replacing animal- and petroleum-based leathers in the fashion industry. Mycelium composites, by contrast, are highly versatile and currently have applications and potential in architecture, insulation, packaging, interior design, and product design.

The properties of mycelium-based materials can be influenced by the choice of fungal strain, the composition of the substrate, the growth conditions, and post-processing treatments. Their most notable characteristics include biodegradability, thermal and acoustic insulation, fire resistance, and sensitivity to moisture. A further advantage is that they can be directly grown into shape or even 3D-printed, allowing the production of a finished object to occur simultaneously with the cultivation of the raw material. (Karana E. 2018, Farias G. 2024, Márföldi 2021, Brittnék A. 2024)

## **PRECEDENTS IN PATTERNING AND SURFACE DESIGN**

The patterning of mycelium surfaces can be carried out either during the growth phase or through post-processing. In our review of precedents, we highlight several outstanding international examples.

### **Gabriela Farias – Mycelium Wool Panels**

Gabriela Farias graduated with a Master’s degree in Arts from Aalto University in 2024, and is currently the lab manager at SPORE (ECO Consult Foundation), working on mycelium-based design solutions and knowledge sharing. One of her main projects is the blending of traditional mycelium substrates with wool (see Fig. 1), which not only influences the visual qualities of the products but also enhances their acoustic and thermal insulation properties. In the composite panels available in the company’s webshop ([spore.nl](http://spore.nl)), it can be observed how different mixtures of substrates and varying degrees of surface overgrowth generate distinctive patterns. The outcome is equally the result of the designer’s intervention and the autonomous growth of the fungus. (Farias G. 2024)



Figure 1: Mycelium-Wool Panels designed by Gabriela Farias (source: [spore.nl](http://spore.nl))

### **Andrea Brittnék – Visual Form Experiments, Reliefs**

Andrea Brittnék is a Hungarian graphic designer and visual communication artist who focuses on material experiments with mycelium and their artistic applications. She obtained her DLA degree at the Doctoral School of the Hungarian University of Fine Arts. Her works are not only visual; scents, textures, and tactile surfaces are integral parts of the concept. In her experiments (see Fig. 2) with mycelium, she uses die-cut forms to create surface shapes, patterns, and formations. Through special lighting, she monitors fruiting body development from its earliest phases, adapting the growth duration to affect the mycelium’s surface qualities. She also concluded that mycelium surfaces can be embossed, pressed, hot-stamped, and grown into form. (Brittnék A. 2024)

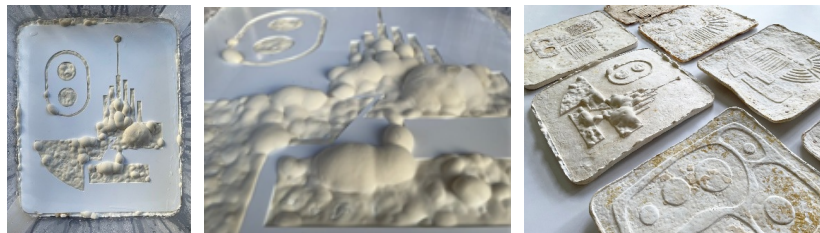
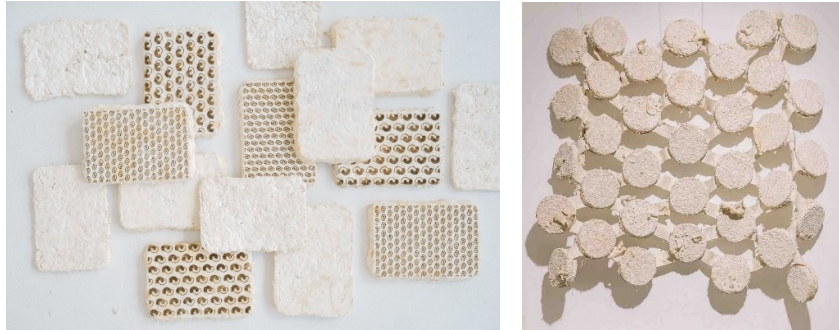


Figure 2: Reliefs by Andrea Brittnék (source: Brittnék 2024)

### **Dóra Márföldi – Experiments and Artistic Projects**

Dóra Márföldi is a Hungarian textile designer, PhD student at the Breuer Marcell Doctoral School, and founder of Szimbiolab. Her practice centers on mycelium-based composites, characterized by collaboration and co-creation with fungi. She places great emphasis on recycling textile waste into mycelium composites, alongside raising awareness and education. In her experimental and artistic works, both craft and industrial technologies appear. She creates different surfaces by varying substrate particle size and density of colonisation, and has also experimented with patterning through laser engraving (see Fig. 3). (Kis-Baraksó A. 2024, Márföldi D. 2024, Márföldi D. 2021)



*Figure 3: Laser-engraved patterns and exhibition piece by Dóra Márföldi (source: Szimbiolab facebook and futurematerials.mome.hu/2024)*

### **Alea Work – Experimental Artistic Projects**

Alea Work is a Paris-based experimental design and material research studio, founded in 2021 by Miriam Josi and Stella Lee Prowse after completing their MSc in Nature Inspired Design. Their practice revolves around mycelium and sustainability. In combining composites, special attention is given to aesthetic value and experimentation. One figure illustrates methods of combining mycelium composites with rocks, while another presents an experiment where mycelium was grown on denim, producing a distinctive patterned surface (see Fig. 4). (Aleawork 2025)



*Figure 4: Transforming Stone and Mycelium Patterns, experiments by Alea Work (source: aleawork.com)*

### **Atanas Enev, Biomyc – Product Development and Material Experiments**

Atanas Enev is the founder and chief designer of Biomyc, a Sofia-based company. His work focuses on sustainable packaging and automotive interiors. Mycelium-based composites are often combined with paper and cardboard, and he experiments with laser engraving, coatings, and dyeing. He seeks the most sustainable solutions while keeping aesthetics and user experience in focus. For the Kia automotive company, he carried out extensive research and numerous experiments (see Figure 5) to address the challenge of coloring mycelium composites, developing methods to achieve precise and consistent shades on the material. (IntelliNews 2025)



Figure 5: Colouring, dying experiments for Kia by Atanas Enev (source:Biomyx LinkedIn post 2025)

### **Aniela Hoytink – Textile and Fashion Design**

Aniela Hoytink is a Dutch textile designer and founder of NEFFA, a company dedicated to producing mycelium-based textiles. One of her best-known works is the Neffa Dress (see Figure 6), composed of thin, sheet-like mycelium elements. The sheets were placed together while still alive, enabling them to fuse and form a continuous surface. As the material is built up modularly from identical elements, it is easily adaptable and repairable. The resulting layered structure, combined with the natural texture of mycelium, creates a unique visual experience. (Frearson A. 2016)



Figure 6: Neffa Dress by Aniela Hoytink (source: aniela Hoytink.com)

### **EXPERIMENTS**

Our experiments were conducted on different substrates, including paper waste, sawdust, and straw, both separately and in mixtures. After shredding, hydrating, and sterilising the substrates, they were inoculated with *Pleurotus ostreatus* and *Herichium erinaceus* mycelium. The cultivation phase consisted of three stages: first in the container used for sterilization, then in molds to take on specific shapes, and finally outside the molds to allow proper oxygen exposure and the formation of a surface mycelium layer. As post-processing, the samples underwent heat treatment.

#### **Molding**

Colonized substrates were placed in various containers, including glass and plastic vessels. In both cases, the mycelium adapted well to the container shapes and adhered partially to the surfaces. Removal was easier from flexible plastic containers, but in all cases it is advisable to design molds with easy demolding in mind.

Mycelium composite blocks exhibited two distinct surfaces: the underside, in contact with the mold, reflected the smoothness or texture of the container, while the top side, exposed to oxygen, developed a skin-like layer with uneven bulges (see Fig. 7). The results confirmed that mycelium composites are moldable, enabling the production of three-dimensional forms and panels.

#### **Hot Pressing**

When post-processing involved pressing in addition to heat treatment, denser, more compact, uniform, and smoother samples were obtained. Without pressing, intriguing relief-like surfaces emerged, resulting partly from substrate particles and unevenness, and partly from the irregular densification of the mycelium (see Fig. 8).



Figure 7: Molded mycelium composite block



Figure 8: Bumpy surface of a mycelium composite

### Laser Engraving

Patterns were created on the surface of heat-treated mycelium composite samples using an Alpha Laser LCE-2 laser cutting and engraving machine, equipped with a 100 W CO<sub>2</sub> laser source. Samples with high paper content could not be tested, as their loose structure and weak colonization led to burning. Sawdust-based samples, however, responded well, and various settings were tested (see Fig. 9). Energy levels above 20% burned the samples severely, damaging their structure so that they crumbled easily. Surface irregularities and the uneven distribution of mycelium also affected the engraved image, causing interruptions or darker burn marks in some lines. Overall, the technology proved suitable for enhancing visual qualities, though optimal settings must be determined in each case.



Figure 9: Laser engraved mycelium composite blocks

### Fruiting Body Formation

In some samples, hyphal knots, pinheads, and primordia (fungal developmental stages) could be observed on the surface (see Fig. 10), and in some cases even fruiting bodies formed. This confirms that the composite can continue to develop as a living material if not inactivated by heat treatment. While this phenomenon may be fascinating for bio-design and artistic purposes. Practical use requires

heat treatment, which eliminates the vivid, dynamic appearance. Fruiting bodies may be seen as exciting by some viewers, while others may find them disturbing or repellent.



Figure 10: Fruiting body formation on the surface (left: *Pleurotus ostreatus*, center: *Hericium erinaceus* live, right: *Hericium e.* after heat treatment)

## CONCLUSION

The precedents presented in this paper demonstrate the diversity of mycelium-based materials, showing how the choice of substrates and blended materials not only influences their physical properties but also shapes their aesthetic qualities. These emerging materials point toward a new aesthetic paradigm that is not yet universally accepted by users. For mycelium-based materials to become widely adopted, it is not enough to improve their mechanical and physical characteristics; their visual qualities must also be refined. Surface treatment and patterning can significantly increase their cultural and commercial value, positioning them as materials of the future.

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# **MATERIALS WITH A NEGATIVE REFRACTIVE INDEX: THEORETICAL FOUNDATIONS, REALIZATION, AND CONTEMPORARY APPLICATIONS**

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## **ABSTRACT**

The study of materials with a negative refractive index represents one of the most significant research directions in contemporary electromagnetics and photonics, as it enables physical phenomena that do not occur in natural media. These include negative refraction, the reversed (inverse) Doppler effect, and the propagation of electromagnetic waves in which the phase velocity and the direction of energy transport are antiparallel. These phenomena were theoretically predicted in the second half of the twentieth century, while their experimental realization became possible through the development of metamaterials – artificially structured systems whose electromagnetic properties are governed primarily by their geometry rather than by their chemical composition alone. In this paper, the fundamental theoretical principles leading to the emergence of a negative refractive index are examined, with particular emphasis placed on the relationship between dielectric permittivity and magnetic permeability, as well as on the role of phase and group velocities of electromagnetic waves in such media. The technological development and fabrication methodologies of metamaterials are also analyzed, including micro- and nanostructured approaches and their associated experimental limitations. Special attention is devoted to contemporary applications of negative-refractive-index materials in super-resolution microscopy, optical cloaking, telecommunications, and the development of functional photonic components, together with a discussion of possible directions for future research.

**Key words:** negative refractive index, metamaterials, negative refraction, electromagnetic parameters, photonics

## **INTRODUCTION**

The development of modern electromagnetic theory and optics over recent decades has led to the emergence of a new class of artificially structured materials whose properties exceed the limitations of natural media. Among these materials, those exhibiting a negative refractive index occupy a particularly prominent position, as electromagnetic waves propagate within them in a manner fundamentally different from that observed in conventional optical systems. Such materials are characterized by phenomena including negative refraction, the inverse Doppler effect, and the propagation of electromagnetic waves for which the phase velocity and the direction of energy transport are antiparallel.

The theoretical foundation for understanding these phenomena was established by Veselago in the 1960s [1], whereas the practical realization of these concepts became feasible only with the development of micro- and nanofabrication technologies. These advances enabled the creation of metamaterials – structures whose electromagnetic properties arise primarily from their geometry rather than from the intrinsic microscopic properties of the constituent materials. As a result, a new chapter has been opened in the fields of photonics and light engineering.

The aim of this paper is to provide a concise overview of the theoretical foundations of negative refractive index phenomena, to analyze the principles of metamaterial design and realization, and to

examine their contemporary and potential applications in optics, telecommunications, and advanced photonic systems.

## **PHYSICAL PRINCIPLES OF NEGATIVE REFRACTION**

The theoretical concept of materials with a negative refractive index is based on the occurrence of negative values of the effective dielectric permittivity and magnetic permeability ( $\epsilon, \mu < 0$ ) within a certain frequency range. In such media, the phase velocity vector and the Poynting vector of an electromagnetic wave are oriented in opposite directions, leading to the formation of so-called “left-handed” electromagnetic waves [1]. This behavior represents a clear departure from the conventional response of electromagnetic fields in natural materials, for which  $\epsilon$  and  $\mu$  are generally positive.

The mathematical description of wave propagation in a medium with a negative refractive index is based on the dispersion relation linking the wave vector to the electromagnetic parameters of the medium. Refraction in such materials is negative and follows an inverted Snell–Descartes law, thereby enabling control over wave propagation in ways that are not achievable in conventional optical media.

## **CHARACTERISTICS OF METAMATERIALS**

Materials exhibiting a negative refractive index do not occur naturally and are instead realized as artificially structured metamaterials, whose electromagnetic properties are determined, as previously stated, by the geometry of their micro- and nanostructures rather than by their chemical composition [2].

The most common implementations involve periodic arrays of metallic resonant elements, such as split-ring resonators and metallic wire grids. The fundamental design principle of these structures is the generation of controlled electric and magnetic resonances within a desired frequency range. Geometrical parameters, including element dimensions, periodicity, and layer arrangement, directly influence the effective values of  $\epsilon$  and  $\mu$ . In this way, the electromagnetic response of the material can be engineered in accordance with predefined requirements.

## **EXPERIMENTAL REALIZATION AND FABRICATION**

The realization of metamaterials exhibiting a negative refractive index requires highly precise micro- and nanofabrication technologies [2]. In the microwave frequency range, such structures are commonly fabricated using standard printed circuit board technologies, whereas lithographic and deposition techniques are employed in the terahertz and optical regimes. These methods include electron-beam lithography, focused ion beam processing, and layer-by-layer deposition of metallic and dielectric materials [3].

Experimental verification of negative refraction is most often performed by measuring the refraction angle at the interface between a conventional medium and the metamaterial, as well as through the analysis of the phase and amplitude characteristics of propagating waves. The observation of opposite directions of phase and group velocities constitutes a key experimental signature of the existence of a negative refractive index.

## **ELECTROMAGNETIC PHENOMENA IN MEDIA WITH NEGATIVE REFRACTIVE INDEX**

Media with a negative refractive index exhibit a variety of unusual electromagnetic effects that have no direct counterparts in classical optics. Among the most significant are negative refraction, the inverse Doppler effect, and the reversed Cherenkov effect. In addition, substantial modifications occur in the behavior of evanescent components of the electromagnetic field, including their amplification.

One of the most important theoretical consequences is the possibility of forming a “superlens” capable of surpassing the diffraction limit of conventional optics [3]. This effect is based on the ability of metamaterials to enhance decaying wave components, thereby enabling subwavelength resolution in imaging processes.

## **CONTEMPORARY APPLICATIONS**

Applications of materials with a negative refractive index are being actively explored in the fields of micro- and nano-optics, telecommunications, sensor technologies, and biomedical imaging. A particularly promising area is the development of plasmonic structures that enable extreme localization of electromagnetic fields and enhanced sensitivity of optical sensors.

In telecommunications systems, such materials offer the potential for the development of more compact antennas, waveguides, and filters with unconventional propagation and dispersion characteristics. In the field of non-invasive diagnostics, metamaterial-based lenses show significant potential for improving resolution and contrast in imaging systems.

## **TECHNICAL LIMITATIONS AND CHALLENGES**

Despite their significant potential, the practical application of materials with a negative refractive index faces substantial technical challenges. One of the key issues is the presence of considerable losses due to dissipation in metallic components, particularly in the optical frequency range, where pronounced heating and reduced efficiency occur.

Additional challenges include narrow operational bandwidths, strong dispersion, and limitations related to fabrication scalability. Structural stability, sensitivity to fabrication tolerances, and the complexity of integration with existing photonic components further represent limiting factors for broader industrial adoption [4].

## **PERSPECTIVES OF FUTURE DEVELOPMENT**

Future research directions are focused on the development of metamaterials with improved energy efficiency, as well as on the introduction of active and reconfigurable structures [4]. Integration with graphene, phase-change materials, and topological insulators opens new possibilities for dynamic control of the refractive index.

Of particular importance is the development of three-dimensional metamaterials and volumetric structures, which enable more complex manipulation of wavefronts. It is expected that future studies will increasingly emphasize practical implementations within commercially available technologies.

## CONCLUSION

Materials with a negative refractive index represent a specific class of artificially structured media whose electromagnetic response differs fundamentally from that of natural materials. The occurrence of simultaneously negative effective values of dielectric permittivity and magnetic permeability leads to a series of unusual effects, including negative refraction and opposite directions of phase velocity and energy transport.

In this work, the theoretical principles underlying negative refraction, the characteristics of metamaterials, and their experimental realization have been discussed, together with the key technological challenges that limit their practical application. Among these challenges, dissipative losses, narrow operational bandwidths, and the complexity of integration with existing photonic systems are of particular importance. Further research aimed at reducing losses and extending the operational frequency range remains of key importance for the development of functional metamaterial-based structures.

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## MODULARITY AS A SUSTAINABLE DESIGN STRATEGY

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### ABSTRACT

*Fashion plays a central role in contemporary society, not only through the production of garments and their environmental impact at the end of the product lifecycle, but also through the complex economic, cultural, and social dynamics it generates. Within this context, modular design emerges as a significant strategy for developing complex systems composed of configurable, separable, and adaptable modules that have the potential to enhance sustainability within the fashion industry.*

*The modular approach enables increased product flexibility, extended garment lifespan, and waste reduction through reconstruction and adaptability. At the same time, it redefines the relationship between designer and user, positioning the consumer as an active participant in the creation and transformation of products.*

*Based on a review of scientific literature and an analysis of professional case studies, this paper categorizes contemporary implementations of modular fashion design, with particular attention to system architecture and module organization. It also identifies key opportunities and limitations of this approach in relation to environmental, economic, cultural, and social sustainability.*

*The findings highlight the need for further interdisciplinary research, including the development of new business models and the integration of Industry 4.0 technologies. A design-led approach is emphasized, focusing on the integration of product and service development as well as shifts in consumption behavior, in order to support more sustainable systems within the fashion industry.*

**Key words:** modular design, fashion, sustainability, circular economy, interdisciplinary approach, Industry 4.0, consumer behavior.

### INTRODUCTION

The fashion industry, particularly garment production, is one of the most resource-intensive sectors, with significant impacts on consumption patterns and end-of-life product management. Within its current linear structure, the system generates substantial waste streams, including post-consumer textile waste, which often ends up in landfills. Overproduction and overconsumption further intensify environmental degradation while simultaneously affecting social, cultural, and economic dimensions of sustainability in an interconnected manner.

A considerable portion of environmental impact is generated during textile production, including fiber processing, material treatments, and fabric manufacturing. However, a substantial share of the environmental burden also occurs after purchase, during garment use, maintenance, and disposal. Despite growing interest in reuse and recycling initiatives, end-of-life strategies remain limited and often localized, highlighting the need for more systemic circular solutions. Extending garment lifespan and designing for disassembly and recyclability are therefore recognized as highly effective strategies for reducing environmental impact.

Design decisions made at early development stages are responsible for a significant portion of a product's total environmental footprint and strongly influence supply chain structures. Consequently, design for modularity and transformation is increasingly recognized as a key strategy for enabling sustainable fashion systems. Transformable design allows garments to be modified both functionally and aesthetically, increasing multifunctionality through reconstruction and adaptation processes. This approach shifts the garment from a static product to an evolving system that can be continuously reshaped during use.

## **MODULAR DESIGN IN FASHION SYSTEMS**

Modularity is a design strategy used to create complex systems from independent components that can be configured through standardized interfaces. In such systems, modification of one module does not compromise the integrity of others, but rather enables alternative configurations and extended functionality over time. A modular product is therefore structured into subsystems with defined interdependencies that allow assembly and disassembly without loss of operational performance.

This design approach supports product variety and adaptability, enabling components to be replaced, updated, or recombined across different contexts of use. As a result, modular systems require strategic planning across production and consumption phases, as well as efficient coordination of design and manufacturing processes. Modular products must be conceived early in the design process, taking into account their full lifecycle, including pre-production, production, use, and end-of-life phases. In addition, modular design can positively influence environmental, economic, and social sustainability by extending product lifespan and reducing material waste.

The architecture of modular products is defined by the relationships between components and their functional, physical, and aesthetic interactions. Interface systems enable configurability and the creation of product families based on shared platforms. Within fashion design, modular garments consist of components that can be assembled and disassembled through various connection systems, forming adaptable collections that respond to functional needs, user preferences, and changing aesthetic trends.

## **TYOLOGIES OF MODULAR FASHION SYSTEMS**

Existing research and practice identify several approaches to modular fashion design. These include systems based on shared components, interchangeable components, cut-to-fit configurations, bus-structure systems, sectional modularity, and mixed modular systems. Although widely applied in other industrial sectors, these approaches remain underexplored within fashion design as a coherent system.

Modular fashion systems can be categorized according to their architectural logic, level of user interaction, and degree of configurability. Some systems rely on pre-defined combinations with limited user intervention, while others actively engage users in assembly, transformation, or customization processes. These approaches vary in complexity, from simple detachable elements to fully user-assembled garments

## **USER INTERACTION AND TRANSFORMABLE GARMENTS**

One category of modular fashion is based on transformation through wear and styling rather than physical interfaces. In this case, garments are designed as part of a continuous system where transformation is achieved through manipulation techniques such as layering, folding, wrapping, and tying. No mechanical connection system is required, and adaptability is largely dependent on user

creativity. This approach enhances personalization and encourages diverse styling outcomes from a single garment system.

Another category includes garments with removable components such as sleeves, collars, or extensions, enabling adaptation to functional needs and environmental conditions. Historical and contemporary examples demonstrate that detachable clothing elements have long been used to extend garment lifespan, improve functionality, and support aesthetic variation. In modern applications, such systems often use zippers, buttons, or hidden fastening mechanisms to enable modular reconfiguration.

A further development of modular fashion involves user-driven assembly systems. In these cases, garments are designed as kits composed of pattern-based components that users assemble independently, often without specialized tools. This approach fosters active user participation, strengthens emotional attachment to garments, and supports extended product use. Digital fabrication technologies, such as laser cutting and on-demand production, further enable personalized modular systems that can be manufactured and assembled outside traditional industrial workflows.

## **GEOMETRIC AND RECONFIGURABLE MODULAR SYSTEMS**

Advanced modular systems explore the decomposition of garments into geometric or structural units that can be recombined into multiple configurations. These systems may rely on fixed base elements combined with interchangeable modules or fully flexible systems where components can be rearranged freely.

Interaction within such systems is typically enabled through mechanical interfaces such as zippers, buttons, or connectors, designed to simplify user engagement while encouraging creative experimentation. The designer defines the structural logic, while the user participates in the final configuration process, resulting in dynamic and personalized outcomes.

Some experimental systems consist of a high number of modular elements designed to generate multiple stylistic variations through recombination. Other approaches explore color-blocking and morphological composition prior to garment assembly, treating design as a two-stage process: first abstract composition, then adaptation to the human body.

## **MODULAR INTERFACES AND CONFIGURABLE GARMENT SYSTEMS**

The variability of modular configurations is enabled through mechanical interfaces, often based on fastening systems such as snap buttons or similar connectors. These interfaces allow modules to be detached, repositioned, and recombined, enabling multiple structural and functional outcomes within a single garment system. From a design perspective, this requires precise alignment of seam lengths and structural proportions across different garment types and fabric categories to ensure full compatibility of modular elements. Within such systems, components such as collars may be transformed into cuffs, while bodice elements may be reconfigured into lower garment sections, demonstrating a high degree of structural adaptability.

Some advanced modular collections consist of a large number of interchangeable components that can be combined to form complete garments or multiple variations of jackets, skirts, and other clothing types. In these systems, digital fabrication technologies such as 3D printing are integrated with textile substrates, allowing material deposition onto perforated fabrics. This hybrid approach enhances garment properties such as lightness, breathability, comfort, and aesthetic variation. Additionally, computational design processes and body mapping techniques enable precise positioning of modules based on anatomical structures, ensuring ergonomic fit and personalized adaptation.

Another approach to modular fashion is based on geometric tessellation, where garments are constructed from repeated minimal units such as triangles, squares, or hexagons. These micro-modules are interconnected through integrated textile interfaces, often created via laser cutting or structural incisions. In this type of sectional modularity, all components share a common interface system, allowing flexible assembly into both flat and three-dimensional textile structures. The configurability of such systems is not predetermined into a single garment form but emerges through user interaction and creative manipulation of geometric units. Depending on the level of design constraint, configuration may be partially or fully delegated to the user, enabling a spectrum of co-creative outcomes.

Materials commonly used in this approach include synthetic textiles such as felt and neoprene, which maintain structural integrity after laser cutting and resist fraying. These materials also support durable interlocking mechanisms that remain stable under repeated assembly and disassembly cycles.

Experimental approaches within this category explore triangular modular systems derived from circular geometries, as well as hybrid tessellations combining multiple geometric forms. Laser-cut interfaces allow for increased precision and complexity but often require material choices that support structural stability and edge durability. Further material explorations involve multilayered textile composites designed to achieve specific functional and aesthetic properties. However, such constructions may present challenges in terms of end-of-life disassembly and recyclability due to their integrated material composition. Other systems explore mathematically driven tessellations that generate diverse spatial configurations and dimensional variations. Open-source platforms compiling modular fashion experiments demonstrate the growing interest in additive and subtractive manufacturing approaches. In these systems, digital fabrication is often combined with manual assembly, resulting in hybrid production models that merge machine precision with human craftsmanship.

Some advanced approaches integrate computational algorithms to calculate the number of modular units required for personalized garment construction. In such cases, individual modules are machine-cut, while final assembly is performed manually using 3D-printed connectors or textile-based fastening systems. This enables the creation of customized garments that combine multiple materials within a single coherent structure.

Additive manufacturing technologies further expand modular design possibilities by enabling the direct production of garment components through 3D printing. Due to printer size limitations, garments are typically constructed from multiple printed units that are later assembled using mechanical or thermal bonding techniques. Once assembled, these systems may become permanent or semi-permanent structures, depending on the connection method. Alternative approaches also explore modular forms designed for manual assembly and disassembly, enabling flexible reconfiguration.



*Figure 1: Example - transformable jacket*

## **FINAL REFLECTIONS ON MODULAR FASHION SYSTEMS SOCIAL SUSTAINABILITY AND USER-CENTERED DESIGN**

The analysis indicates that modular fashion currently operates primarily within research contexts and small-scale design practices rather than large-scale industrial production. Key barriers to broader adoption include the need for fundamental changes in design methodologies, production systems, garment aesthetics, user behavior, and business models.

At the same time, emerging technologies associated with advanced digital manufacturing and Industry 4.0 offer significant potential to enhance the feasibility and scalability of modular fashion systems. These technologies can support more efficient production processes, higher customization levels, and improved integration between design, manufacturing, and user interaction. Overall, modular fashion presents a promising framework for the future of sustainable garment design, combining creative experimentation, technological innovation, and systemic sustainability thinking. However, its widespread implementation will require coordinated interdisciplinary efforts and structural transformation across the fashion industry.

### **SOCIAL SUSTAINABILITY AND USER-CENTERED DESIGN**

From a social sustainability perspective, modular fashion introduces inclusivity and personalization into garment design. Widely applied “cut-to-fit” strategies allow modules to be dimensionally adapted to individual body measurements, either through mathematical tessellation systems or parametric pattern adjustments. This adaptability enables garments to respond to changes in body shape, reducing stigma associated with size variation and improving accessibility across diverse user groups.

Beyond physical adaptation, modular systems also support stylistic and aesthetic flexibility, enabling users to modify garments according to personal preferences and contextual needs. However, successful implementation of such systems depends on consumer acceptance and requires integration with service-based models supported by Industry 4.0 technologies. In particular, artificial intelligence and the Internet of Things (IoT) can enhance interoperability across supply chain actors, improve production feasibility, and enable scalable customization models.

### **DESIGN, CONSUMPTION, AND BUSINESS MODEL TRANSFORMATION**

Modular garment design also represents an opportunity to enhance creative flexibility within the design process, enabling continuously evolving forms and styles through adaptable systems. This approach supports the development of flexible collections that can be updated over time rather than replaced seasonally. However, the transition to modular fashion requires significant changes in design methodologies, prototyping practices, production systems, and distribution strategies. It also demands new business models that prioritize user engagement, localized production systems, and long-term consumer relationships. Such models must support both acquisition and post-purchase interaction phases, ensuring continuous user engagement throughout the garment lifecycle.

From a cultural sustainability perspective, modular fashion extends the role of design beyond product creation to include post-purchase interaction systems and services. These systems can include participatory tools, instructional kits, and digital platforms that guide users in garment transformation and maintenance. Despite their conceptual development, such service ecosystems remain largely underexplored in industrial practice. Future strategies should therefore aim to reshape consumer behavior and promote more conscious consumption patterns through education and interaction design.

Although consumer interest in modular fashion is still limited in scope, existing studies indicate positive responses to concepts such as reparability, customization, and stylistic adaptability. At the same time, concerns remain regarding aesthetic acceptance, functional complexity, and perceived usability. Additional barriers include novelty perception and potential cost increases. These challenges highlight the need for further empirical research on long-term user attachment to modular garments, as well as studies quantifying the relationship between modular design and reductions in consumption and production volumes. Moreover, new business model exploration is essential for enabling industry adoption, as current fashion systems remain largely linear and resistant to radical structural change.

## **INDUSTRY STRUCTURE AND TECHNOLOGICAL ENABLEMENT**

The reluctance of fashion companies to adopt modular systems is also linked to limited economic incentives within existing linear production models. Nevertheless, modularity has the potential to improve customer loyalty, enable economies of scale, and reduce overproduction and waste.

Industry 4.0 technologies play a critical role in enabling this transition. Digital tools can support rapid prototyping, optimize lifecycle management, and facilitate mass customization based on anthropometric data and user preferences in material, color, and form. Additionally, RFID technologies can be embedded into modules to enable product tracking across the lifecycle. Despite these advancements, current applications remain largely experimental or conceptual, with limited real-world industrial implementation. Most existing projects focus on technological feasibility rather than full-scale system integration.

Garments produced through 3D printing and modular fabrication present both advantages and limitations. While digitally manufactured modules often exhibit high structural durability, they frequently suffer from reduced comfort, breathability, and flexibility. Similarly, laser cutting enables high-precision modular systems based on digital geometries, but it is primarily suitable for synthetic or non-woven materials that do not fray easily. However, material bonding techniques such as adhesive layering, while improving comfort and finishing quality, introduce significant challenges for end-of-life disassembly and recyclability. This directly affects the circularity of modular systems and complicates material recovery processes.



*Figure 2: Examples convertible dresses*

Fashion plays a central role in contemporary society not only through garment production and end-of-life impacts, but also through its broader cultural, ethical, and economic influence. Clothing is not merely a material object but a complex system embedded within interconnected social and environmental dynamics. Therefore, advancing modular fashion requires multidisciplinary research that integrates design innovation, technological development, and sustainable business strategies. Future developments should focus on improving scalability, enhancing interoperability across supply chains, and supporting user-centered design approaches enabled by Industry 4.0 technologies. Only through such integrated frameworks can modular fashion evolve from experimental practice into a viable and impactful model for sustainable transformation of the fashion industry.

## **CONCLUSION**

Modular fashion emerges as a promising design strategy that addresses key environmental, social, and cultural challenges within the contemporary fashion industry. By enabling configurability, disassembly, and transformation, modular systems extend garment lifespan, reduce textile waste, and encourage more responsible patterns of consumption. At the same time, they redefine the role of the user, shifting it from passive consumer to active participant in the design and transformation process.

Despite these advantages, the implementation of modular fashion at an industrial scale remains limited. Barriers include material constraints, interface design complexity, challenges in end-of-life recyclability, and the lack of scalable business models. Additionally, consumer acceptance and usability concerns still need to be further explored through empirical research.

The integration of Industry 4.0 technologies, such as digital fabrication, artificial intelligence, and IoT-based systems, offers significant potential to overcome these limitations by enabling customization, improving production efficiency, and enhancing supply chain interoperability. However, current applications remain mostly experimental or conceptual.

In conclusion, modular fashion represents a viable pathway toward more sustainable and circular clothing systems, but its full potential can only be achieved through interdisciplinary collaboration between design, technology, and industry, alongside a fundamental shift in production and consumption paradigms.

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## THE APPLICATION OF MODULAR DESIGN IN THE FASHION INDUSTRY

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### ABSTRACT

*Modular design is a design approach that enhances the functionality and aesthetic diversity of clothing by allowing garments to be reconfigured through interchangeable components. This concept not only increases the visual and stylistic versatility of clothing but also actively involves the wearer in the design process by enabling personal choice and customization. Furthermore, modular design contributes to extending the lifecycle of garments, thereby reducing waste and promoting sustainability.*

*In the context of the fast fashion market, modular design represents a potential breakthrough strategy that helps reconcile the demand for contemporary fashion with the requirements of low-carbon and environmentally responsible production. By integrating flexibility and adaptability into garment construction, it supports a more sustainable approach to fashion consumption. This paper analyzes existing examples of modular fashion and categorizes modular design into three main types: component-based modular design, geometric modular design, and compound modular design.*

**Key words:** Modular design, fashion industry, fast fashion, sustainability

### INTRODUCTION

With the rapid advancement of the global economy and continuous improvement in living standards, significant changes have emerged in consumer behavior. Increased purchasing power has enabled consumers to place greater emphasis on personal appearance, identity, and fashion expression. In contemporary urban societies, fashion functions not only as a practical necessity but also as a powerful medium of social communication and self-representation, contributing to the emergence and expansion of the phenomenon known as “fast fashion.”

The concept of fast fashion was introduced into the fashion industry during the 1980s as a response to the growing demand for affordable, trend-driven, and rapidly changing clothing. Its primary objective was to democratize fashion by making contemporary trends accessible to a broader consumer base through fast production cycles and low-cost distribution models.

Although this model successfully contributed to the democratization of fashion and the rapid dissemination of trends, its structural characteristic—namely the extremely short product lifecycle—has led to severe environmental consequences. Overproduction, accelerated consumption, and rapid disposal of garments have resulted in massive textile waste generation, increased carbon emissions, and excessive exploitation of natural resources. These issues have raised significant concern among researchers, industry stakeholders, and the general public.

In response to these challenges, the concept of sustainable fashion has gained increasing importance in recent decades. It is grounded in principles of environmental responsibility, waste reduction, and efficient resource utilization. Sustainability is now recognized as a fundamental driver of transformation within the fashion industry and is integrated across all stages of production, including raw material sourcing, textile manufacturing, dyeing processes, product design, packaging, and distribution systems.

Particular emphasis is also placed on post-consumer textile management, which includes recycling, reuse, and creative transformation of discarded garments. Through these practices, the fashion industry is gradually shifting from a linear “take - make - dispose” model toward a circular system that prioritizes product longevity, resource efficiency, and waste minimization.

Within contemporary sustainable design approaches, modular design has emerged as a significant strategy. It enables the construction of garments through interchangeable, adaptable, and reconfigurable components, thereby enhancing product functionality and durability. Although modular design has already been widely applied in fields such as industrial design, electronics, and automotive engineering, its application within fashion design is still evolving and under active exploration.

Due to its inherent flexibility, modular design is often associated with multifunctional design concepts, as it allows a single garment to serve multiple purposes and configurations. However, its potential extends beyond multifunctionality, encompassing personalization, lifecycle extension, resource efficiency, and textile waste reduction.

This paper examines existing applications of modular design within the fashion industry, with particular emphasis on its design principles and environmental implications. Through classification and theoretical interpretation of different approaches, the aim is to expand the understanding of modular design and contribute to the development of innovative and sustainable design practices.

## **ENVIRONMENTAL VALUE AND APPLICATION STATUS OF MODULAR DESIGN**

Modular design is a contemporary design approach based on the decomposition of a product into multiple functional units, known as modules, which can be independently used, replaced, or recombined in various configurations. These modules function as universal elements that can be integrated into different systems, enabling the creation of products with diverse functions, forms, and performance characteristics.

In the context of fashion design, modular design involves deconstructing garments into separate components, where each component operates as an independent module. These modules can be reassembled, reconfigured, and adapted according to user needs. Consequently, clothing is no longer perceived as a fixed and complete entity but rather as a dynamic system composed of interactive elements that allow extensive transformation possibilities.

### **ENVIRONMENTAL VALUE OF MODULAR DESIGN**

The environmental value of modular design is reflected in three key characteristics: diversity, flexibility, and continuity.

Diversity modular design enables multiple aesthetic and functional transformations of garments. By involving users in the selection and assembly of modules, it enhances interaction and strengthens emotional engagement with the product. This shifts the design process from a one-way creation model to a participatory, interactive system. Additionally, different module combinations allow for multiple stylistic variations, increasing product usability and significantly extending its lifecycle at relatively low additional cost.

Flexibility the traditional garment lifecycle includes design, production, distribution, use, and disposal. In contrast, modular garments demonstrate a high degree of flexibility across all stages of this cycle. Manufacturers can adjust module production according to market demand, while consumers may retain only the components they need and replace or discard others. This modular

structure enables efficient resource allocation and reduced energy consumption, aligning closely with low-carbon and sustainable production principles.

Continuity is a distinctive feature of modular design that is not present in conventional garments. Modules can be used not only within a single product but also across different products, collections, and seasonal lines. Standardized modules enable long-term reuse across multiple collections, meaning that components purchased in one season can be combined with new modules in subsequent seasons. This significantly extends product lifespan and maximizes environmental value.

## **APPLICATION OF MODULAR DESIGN IN THE FASHION INDUSTRY**

The application of modular design in the fashion industry is still in an early stage of development and is mainly limited to experimental or isolated cases. In domestic contexts, modular design is primarily used to achieve multifunctionality at the product level, without fully exploring its systemic and long-term potential.

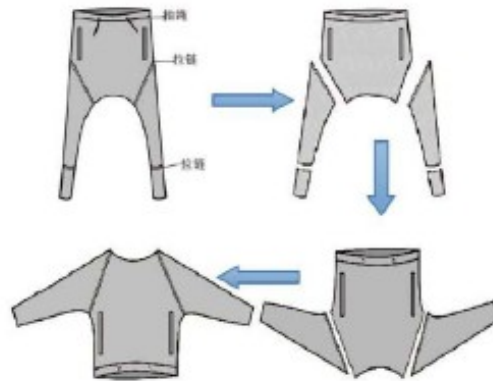
In contrast, international practice demonstrates a more advanced level of development. Abroad, modular design is applied not only at the level of individual garments but also across entire collections and seasonal systems. In some cases, modules are standardized in a way that allows them to function across multiple collections, creating long-term design and production systems. Despite significant conceptual and practical progress, modular design in fashion remains underdeveloped in terms of full commercialization, and its market potential is still not fully realized.

## **MULTI-FUNCTION MODULE**

A multi-function module refers to a type of modular system in which a single module performs two or more functional roles. Unlike basic component-based modular systems, where functionality is achieved through simple disassembly and reassembly, multi-function modules introduce an additional layer of transformation through functional conversion mechanisms. Functional conversion can be achieved through two primary approaches: the opening transformation method and the role transformation method.

Opening transformation method involves the adaptation and alignment of garment openings such as necklines, cuffs, hems, or leg openings. Through this approach, structural elements originally designed for one purpose can be reassigned to another functional position.

For instance, a cuff decorative element may be repositioned and transformed into a neckline decoration. More complex transformations may include the interchange of sleeve and leg openings, or the integration of neckline and hem structures, enabling new functional configurations within a garment.



*Figure 1: Example - multi-function leisure wear design*

This method refers to the conversion of a garment's original functional identity into an alternative role. It involves reversibility, reconfiguration, and structural reinterpretation of garment parts.

Typical examples include:

- reversible garments (inside-out usage),
- transformation of trousers into skirts,
- conversion of sleeves into trouser legs and vice versa.

Design in which the armhole depth is expanded and structurally aligned with the thigh opening, enabling a module to function either as sleeves or trouser legs. This allows a single garment system to shift between upper-body and lower-body functions.

Compared to single-function modular systems, multi-function modules offer significantly greater design freedom but also present higher technical complexity and construction challenges.

Geometric modular design differs from component-based approaches in that garments are deconstructed according to geometric principles rather than functional garment parts. Modules may take the form of triangles, rectangles, squares, or other polygonal shapes, with variations in size and proportion.

Garments can be constructed using either a single type of geometric module or a combination of multiple geometric forms. Assembly methods may be two-dimensional (flat construction) or three-dimensional, providing high structural flexibility.

A key characteristic of this approach is the high interchangeability of modules. When standardized in size, geometric modules function similarly to building blocks, allowing users to recombine them freely. In such systems, modules may also extend beyond clothing to accessories such as bags, belts, or hats.

A representative example is the “zipper dress” by Sebastian Errazuriz, composed of multiple independent zippers that can be partially or fully removed. By modifying the zipper configuration, the garment can transform into multiple stylistic outcomes.

A similar approach is observed in the work of Bolor Amgalan, where geometric modules such as quadrilateral and strip elements are assembled using an embedded construction strategy resembling building blocks.

An important advantage of geometric modular design lies in its resource efficiency. Because the same modules can be reconfigured into new forms, the need for additional material production is reduced, and waste generation during disposal is minimized.

Compound modular design represents a hybrid approach that integrates both component-based and geometric modular systems. Rather than maintaining strict separation, this approach merges both strategies into a unified design framework. Chen Weihong's graduation project "Modular Cycle" illustrates this integration. In this work, the garment body functions as a component-based module, while decorative and structural elements are derived from geometric modular systems. For example, the base dress structure follows a conventional modular framework, while additional elements can function as skirts, capes, or decorative components depending on their configuration. This hybrid strategy enables greater design flexibility, enriched aesthetic expression, and expanded application potential for modular fashion systems.

Module joining systems in modular design in addition to decomposition strategies, the methods used for module assembly represent a crucial aspect of modular design. Connection techniques directly influence durability, usability, aesthetics, and sustainability.

Common joining methods include:

- buttons and snap fasteners (simple and widely applicable),
- zippers (high stability and versatility),
- knots (decorative but structurally weaker),
- embedded systems (innovative but material-dependent),
- thermal adhesive films (convenient but non-reversible and unsuitable for reuse).

While each method offers specific advantages, the selection of joining systems must align with the overall design objectives, particularly in relation to sustainability and the potential for repeated reuse of modules.

## CONCLUSION

It can be concluded that different approaches within modular design may be understood as a design continuum that redefines the relationship between parts and wholes. In component-based modular design, the process begins with the decomposition of a complete garment into functional parts. In contrast, geometric modular design starts from abstract forms and basic geometric units that are subsequently assembled into complex garment structures. Compound modular design represents an intermediate approach that integrates and balances both systems within a unified framework.

Based on the analyzed examples presented in this study, modular design can be defined as an inherently inclusive and highly flexible design strategy. Its core value lies in the high degree of freedom in both disassembly and reassembly processes. Modules may be defined as functional components, geometric units, or hybrid structures, with fluid boundaries between these categories. Furthermore, modular systems enable multi-level application across different design scales, ranging from individual garments to full collections and seasonal fashion lines. This continuity allows the repeated use and recombination of modules across different contexts, significantly extending the lifecycle of fashion products.

In addition, the dimensionality and granularity of modules remain highly adaptable. Modules may be simple or complex, minimal or highly detailed, depending on the intended design objective. This demonstrates that the application space of modular design is extensive and still largely underexplored. In the context of the fast fashion industry, modular design emerges as a promising strategy for balancing aesthetic and market demands with environmental sustainability requirements. However, despite existing research and experimental applications, its full potential has not yet been fully realized, making it an important field for further exploration, innovation, and practical development.

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## **RE-LEARNING FROM WASTE: ARTISTIC PATHWAYS TOWARD REGENERATIVE TEXTILE THINKING**

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### **ABSTRACT**

*This paper explores the integration of regenerative and circular practices in textile design education as a means to reduce material waste and foster sustainable thinking among emerging artists and designers. The research is based on experimental studio projects developed within the West University of Timișoara, Faculty of Arts and Design, where textile waste is reconsidered as a source of creativity, not as residue. Through artistic processes such as upcycling, eco-dyeing, and rust-dyeing, students engage in hands-on learning that redefines their relationship with matter, process, and time. The study emphasizes how re-learning from waste can cultivate ecological awareness, material empathy, and innovative approaches to design education. The results highlight a transformative pedagogical model that merges sustainability with artistic expression, encouraging regenerative textile thinking as a pathway toward responsible creation in contemporary art and design.*

**Keywords:** sustainability, textile waste, art education, circular design, regenerative thinking

### **INTRODUCTION**

The growing environmental impact of the textile and fashion industries calls for systemic educational change. Art and design schools play a crucial role in rethinking the material, aesthetic, and ethical dimensions of textile production. Embedding sustainability within creative education allows students to explore circular processes and develop a deeper understanding of the life cycle of materials. The study presented here investigates how art-based pedagogies can contribute to waste reduction and the development of regenerative textile thinking.

### **THEORETICAL BACKGROUND**

Theoretical approaches to sustainability in textile design education emphasize the intersection of creativity, ethics, and material ecology. According to Fletcher (2012, p. 45), design education must move beyond efficiency and address the values shaping production and consumption. Granata (2021, p. 82) explores the performative dimension of dress and material culture, while Haraway (2016, p. 101) and Tsing (2015, p. 23) introduce relational models of coexistence and regeneration. Within this framework, art and design schools function as laboratories for ecological awareness, where the transformation of matter parallels the transformation of thought. These perspectives provide the theoretical foundation for the practice-led approach adopted in this study, which views material experimentation as a form of ecological pedagogy. These ideas intersect with the broader discourse on textile art and material culture explored by Auther (2010) and Parker (2021), who examine how textile practices challenge the traditional boundaries between art, craft, and gender.

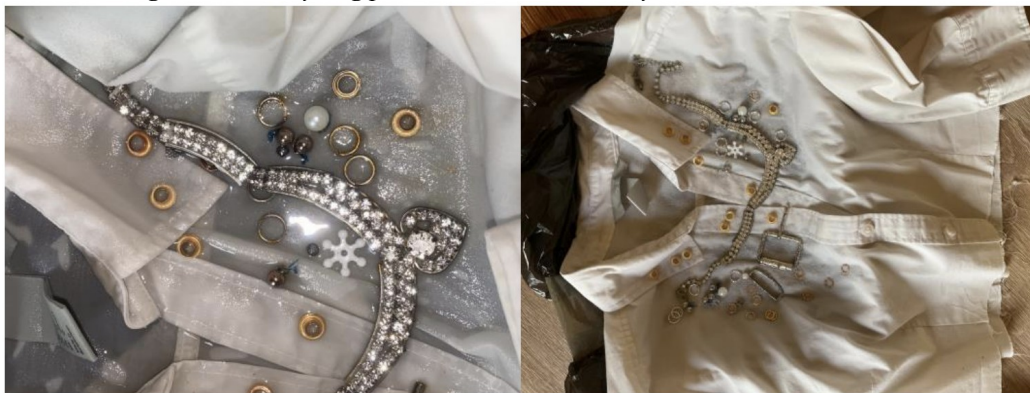
### **METHODOLOGY**

The research methodology is based on practice-led inquiry, integrating artistic experimentation with pedagogical observation. Within the Faculty of Arts and Design at the West University of Timișoara, groups of undergraduate textile students participated in studio-based projects focused on sustainable material transformations. Techniques such as upcycling, eco-dyeing, and rust-dyeing were employed to investigate the aesthetic and environmental potential of discarded materials. The rust-dyeing process was documented in the FAD textile laboratory (Figures 1–3), where students experimented with the transformation of metallic traces into organic patterns. This hands-on exploration not only generated visual outcomes but also deepened students' understanding of material change as a metaphor for regeneration. This approach follows Ingold's (2013, p. 97) notion of "thinking through

making,” allowing students to develop awareness through direct material engagement. Data were collected through reflective journaling, photographic documentation, and collective critiques as means of deepening material literacy and ecological awareness.



*Figure 1. Rust-dyeing process, FAD Laboratory, student: Victoria Rusu*



*Figure 2. Rust-dyeing process, FAD Laboratory, student: Violeta Mujdar*



*Figure 3. Rust-dyeing process, FAD Laboratory, student: Victoria Rusu*

## **FINDINGS AND DISCUSSION**

The results indicate that engaging with textile waste through artistic experimentation can transform students' perception of materials and processes. Participants developed a heightened sense of responsibility, understanding waste as a carrier of meaning and creative opportunity. The hands-on processes encouraged autonomy, curiosity, and critical thinking—key components of sustainable education (Ingold, 2013). Student reflections revealed that working with discarded materials fostered emotional connections with the act of making and reframed the notion of value. This understanding of material transformation echoes the perspectives of Impey (2013) and Lai (2019), who view textile practice as a poetic form of storytelling. Similarly, Quinn (2013) emphasizes the visionary role of textile innovation in shaping sustainable futures. The results (see also Figures 1–3) reflect how the act of reusing rusted materials reshaped students' perception of imperfection, decay, and aesthetic value. By situating material experience within ecological and social contexts, the study affirms that re-learning from waste is not merely a technical challenge, but a philosophical and ethical practice that reshapes design pedagogy. These findings suggest the importance of integrating regenerative practices within contemporary art and design curricula.

## **CONCLUSIONS AND IMPLICATIONS**

This study demonstrates that regenerative and circular thinking can be meaningfully integrated into textile education through artistic methodologies. The pedagogical model developed at the West University of Timișoara shows that sustainability is not an external addition to design education but a transformative framework. The study aligns with contemporary reflections on the regenerative potential of art and design articulated by Parker (2021) and Lai (2019), emphasizing the fusion of ethics and aesthetics within material practice. Future research should further explore interdisciplinary collaborations between art, science, and ecology to expand the reach of regenerative pedagogy in design. Ultimately, re-learning from waste reveals that creative education holds the potential to redefine not only material practices but also the ethical foundations of artistic creation.

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# **THE IMPACT OF TROUSER CONSTRUCTION AND PATTERN DESIGN ON THE COMFORT OF WHEELCHAIR USERS**

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## **ABSTRACT**

*Clothing comfort represents one of the key factors influencing the quality of life of individuals who use wheelchairs. Prolonged sitting imposes specific requirements regarding trouser construction, material selection, and pattern design. The aim of this study is to examine, based on a survey conducted in Serbia, Hungary, and Sweden, the extent to which existing trouser models meet the needs of wheelchair users, as well as to identify the most important problems respondents encounter when wearing standard ready-to-wear clothing.*

*The research was conducted on a sample of 30 respondents 10 from Serbia, 10 from Hungary, and 10 from Sweden of different genders, ages, and mobility levels. The results show that more than 70% of respondents experience discomfort in the waist and hip areas, while 65% report problems with seam pressure while seated. Furthermore, the study identified a significant need for ergonomic adjustments in trouser patterns and the use of elastic, breathable materials that allow greater freedom of movement and reduce pressure.*

*It is concluded that properly constructed trousers significantly contribute to the physical comfort, mobility, functionality, and self-confidence of wheelchair users, as well as to their easier integration into everyday life.*

**Keywords:** wheelchair users, comfort, trouser construction, pattern design, Serbia, Hungary, Sweden

## **1. INTRODUCTION**

Individuals who use wheelchairs face numerous challenges in their daily lives, among which clothing plays a significant role. Standard ready-to-wear garments are designed for individuals who spend most of their time in an upright position, while the needs of wheelchair users are largely overlooked. Prolonged sitting leads to increased pressure on certain parts of the body, reduced circulation, and the occurrence of irritation and pressure sores.

Trousers occupy a particularly important place in adaptive clothing, as they directly affect comfort in the seated position. Inadequate waist height, improperly positioned seams, and unsuitable materials often cause discomfort, pain, and limited mobility. The aim of this paper is to identify key problems and propose guidelines for improving trouser construction for wheelchair users, based on a survey conducted in Serbia, Hungary, and Sweden.

## **2. THEORETICAL FRAMEWORK**

### **2.1. The concept of clothing comfort**

Clothing comfort is defined as the subjective feeling of ease while wearing garments, influenced by physical, thermophysiological, and psychological factors. For wheelchair users, physical comfort is of central importance, as prolonged sitting leads to constant pressure on the gluteal region, thighs, and lower back.

### **2.2. Trouser construction and ergonomic requirements**

Trouser construction includes shaping the basic pattern, seam placement, waistband height, leg width, and pocket location. In standard trousers, the back waist height is often too low for the seated position, causing trousers to slide down and exposing the lower back. Inner seams may create additional pressure and friction, pockets are inaccessible while seated, and rigid materials reduce flexibility and increase discomfort.

Ergonomic trouser design involves adjusting the pattern to the body in seated position and using flat or shifted seams and modified pocket placement.

### 2.2.1. The impact of materials on comfort

The materials used for manufacturing trousers must be elastic, breathable, and soft in order to reduce friction, allow air circulation, and prevent skin overheating.

## 3. RESEARCH METHODOLOGY

### 3.1. Sample of respondents

The research was conducted using a standardized questionnaire from January to March 2025. The sample included 120 respondents—60 from Serbia and 60 from Hungary—who had been using wheelchairs for more than one year. The structure of the sample by country is shown in Table 1.

Country	Number of respondents	Percentage (%)
Serbia	10	33.3%
Hungary	10	33.3%
Sweden	10	33.3%
<b>Total</b>	<b>30</b>	<b>100%</b>

Table 1. Structure of respondents by country

### 3.2. Research instrument

The questionnaire consisted of 18 closed and semi-open questions related to:

- frequency of discomfort caused by trousers,
- most problematic trouser components,
- material preferences,
- satisfaction with available ready-to-wear clothing,
- need for specialized adaptive clothing.

### 3.3. Data processing methods

The data were processed using descriptive statistics and are presented in percentages.

## 4. RESEARCH RESULTS

The most common problems are shown in Table 2.

Problem	Number of respondents	Percentage (%)
Discomfort in waist and hip area	22	73%
Seam pressure in seated position	20	65%
Non-elastic materials	18	60%
Difficulty dressing/undressing	17	57%
Incorrect back waist height	21	70%

Table 2. Most common trouser-related problems among wheelchair users

The high percentage of respondents experiencing discomfort in the waist and hip areas is shown in Figure 1.

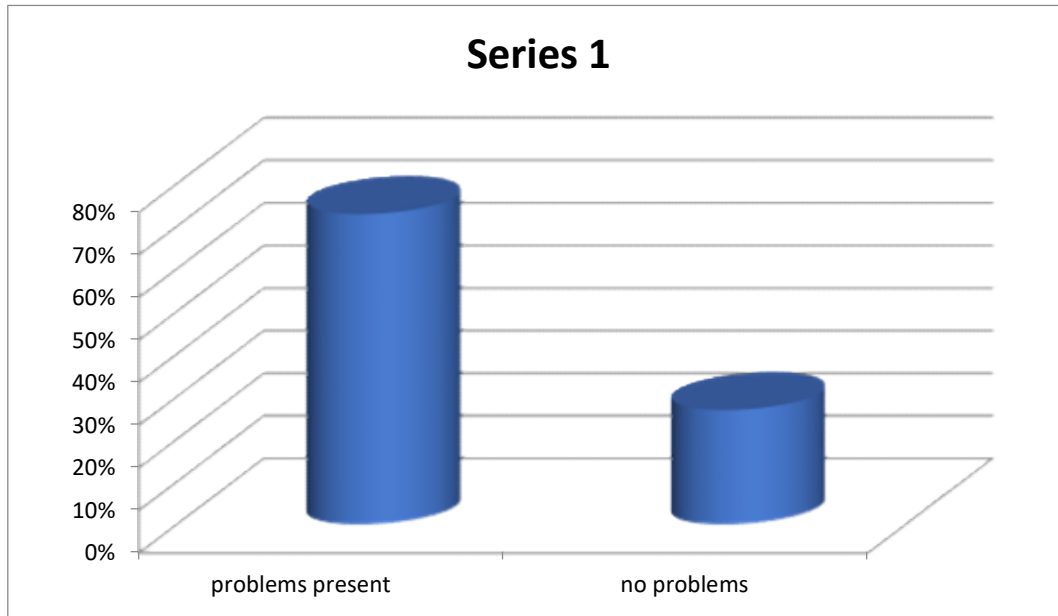


Figure 1: Percentage of respondents experiencing problems in the waist and hip area (bar chart: 73% – problems present, 27% – no problems)

The need for specially designed trousers is shown in Table 3 and visualized in Figure 2.

Table 3. Need for specially designed trousers

Response	Number of respondents	Percentage (%)
Yes	23	76%
No	4	13%
Not sure	3	11%

Table 3. Need for specially designed trousers

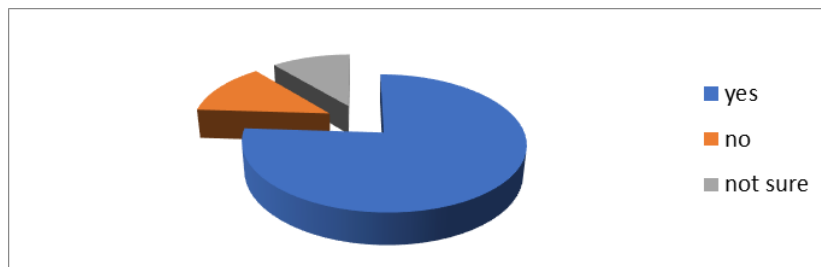
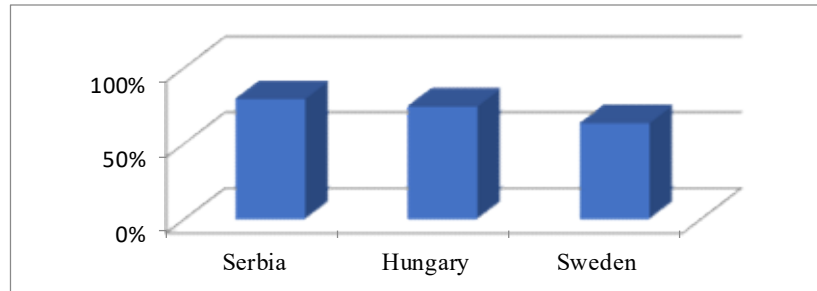


Figure 2: Need for specially designed trousers (pie chart: 76% – yes, 13% – no, 11% – not sure)

A comparison of results between Serbia, Hungary, and Sweden is shown in Figure 3.



**Figure3:** A comparison of results between Serbia, Hungary, and Sweden (*Bar chart: Serbia 80%, Hungary 75%, Sweden 64%*)

## 5. PROPOSED CONSTRUCTION CHANGES AND DEVELOPMENT OF AN ADAPTIVE PATTERN

### 5.1. Main design challenges

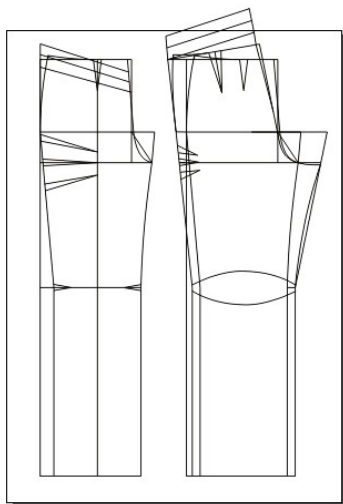
Based on the survey results and insights into everyday difficulties faced by respondents, key challenges in trouser design for wheelchair users were identified. The most significant relate to the inadequacy of the back waistband in the seated position, increased seam pressure, difficulty fastening, inaccessible pockets, and compromised aesthetic appearance.

An additional challenge is balancing functionality with modern design. Respondents emphasized that, besides comfort, they want clothing that is visually appealing and does not differ from standard fashion.

### 5.2. Construction adjustments

The waistband was designed to be higher in the back and lower in the front to increase comfort while seated and prevent trousers from slipping down during use.

Seams were designed to be flat or slightly shifted away from pressure points to minimize friction, irritation, and skin injury. Side or magnetic fastenings were introduced to enable easier dressing and undressing, especially for individuals with limited hand mobility.



**Figure 4:** Changes in trouser construction

Pockets were placed on the inner side of the leg, below the knee, making them accessible while seated yet discreet and visually acceptable.

Soft, elastic, and breathable materials were used to follow body movement, reduce friction, and improve thermal regulation. Changes in trouser construction are shown in Figure 4.

### **5.3. Development and testing of the adaptive pattern**

Based on the construction principles, a specialized trouser pattern adapted for a seated posture was developed. The knee area was shaped to reduce material tension, and the back rise was extended for better body conformity. A side-width adjustment system was added, and the fastening was shifted toward the front leg for easier use. Experimental prototypes were produced and tested under real wearing conditions. Based on feedback, additional adjustments were made. The final design integrates ergonomic functionality with a modern appearance.

### **5.4. Comfort assessment after modifications**

After prototype testing, respondents reported:

- significantly reduced skin irritation,
- easier dressing and undressing,
- increased mobility and sense of security,
- improved self-confidence during wear,
- better thermal regulation due to fabric choice.

These results confirm that construction modifications have a direct and positive impact on trouser comfort and functionality for wheelchair users.

## **6. DISCUSSION**

The survey results and adaptive trouser pattern testing clearly indicate that standard ready-to-wear clothing does not adequately meet the real needs of wheelchair users. The most prominent problems insufficient back waist height, seam pressure, difficult fastening, inaccessible pockets are consistent with earlier research in clothing ergonomics (Morton & Hearle, 1993; Kim, 1999).

The introduction of construction changes higher back waistband, flat or shifted seams, alternative fastening systems, and redesigned pocket placement led to a marked improvement in trouser functionality. A special contribution of this study is the development of a pattern adapted specifically to the seated posture, reducing material tension at the knees and preventing back slippage.

User feedback after prototype testing confirmed reduced irritation, easier dressing, increased mobility, and greater self-confidence. These findings demonstrate that inclusive design does not contradict aesthetics; instead, functionality and modern appearance can successfully coexist.

The study also confirms that collaboration between designers and users is essential for developing practical and innovative solutions in adaptive clothing.

## **7. CONCLUSION AND IMPLICATIONS**

Based on the conducted research, it can be concluded that redesigning trouser construction for wheelchair users significantly increases comfort, functionality, and overall quality of everyday life. Survey and prototype testing results clearly show that even relatively small design modifications such as an adjusted waistband, shifted seams, and alternative fastening systems can lead to substantial improvements in clothing usability.

These findings have important implications for the fashion and textile industries, highlighting the need for broader application of inclusive design principles. Adaptive clothing should not be an exception but rather a standard in modern garment production.

The study is also significant in the educational context, suggesting that inclusive design should be systematically integrated into curricula. Based on the findings, the textile industry in Serbia has genuine potential to become a regional leader in the development and production of adaptive clothing.

Future research will focus on developing smart textile materials, adjustable patterns, and models adapted to gender and different levels of mobility, with the aim of further enhancing dignity, independence, and style for all users.

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## **BIOPIGMENTS AND LIGHT - PHOTOLYTIC MECHANISMS AND APPLICATIONS**

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### **ABSTRACT**

*Biopigments represent a broad group of natural molecules capable of absorbing, transforming, and dissipating light energy. Their photolytic stability and photochemical reactivity are considered key in photosynthesis, photoprotection, biodiagnostics, and in the development of novel, advanced materials that possess specific optical, mechanical, or protective properties. Contemporary research concerning the photolytic mechanisms of chlorophylls, carotenoids, phycobilins, and melanins is summarized in this paper, including direct photolysis, oxidative photodegradation, and mechanisms that are mediated by singlet oxygen. The applications of these processes are presented across biotechnology, photodynamic therapy, the stabilization of food pigments, and the development of photostable biomaterials. Ultimately, the photolytic processes of biopigments are understood as a complex interaction between structural factors, molecular transitions, and environmental conditions.*

**Key words:** biopigments, photolysis, photodegradation, chlorophyll, carotenoids

### **INTRODUCTION**

Biopigments are natural molecules that absorb electromagnetic radiation and perform key physiological, ecological, and biochemical functions. The most significant pigment groups include chlorophylls, carotenoids, phycobilins, and melanin. Under the influence of light, these pigments undergo photolytic and photochemical processes which lead to alterations in their structure and functionality.

Photolytic mechanisms significantly impact photosynthetic efficiency, photoprotection, and the stability of pigment materials used across the food, pharmaceutical, and biotechnology industries. In the textile industry, biopigments are increasingly used as an ecological alternative to synthetic dyes. The stability of these natural colorants when exposed to light (lightfastness) is considered a critical factor for successful commercial application. Research [1,2] highlights the importance of understanding the kinetics of photodegradation within real-world biological and technological systems.

### **OPTICAL PROPERTIES OF BIOPIGMENTS**

Light absorption is fundamentally based on conjugated double bonds, which facilitate electron transitions to higher energy levels [1]. Chlorophylls are known to absorb light efficiently in both the blue and red regions of the spectrum [5], whereas carotenoids primarily absorb within the violet-blue-green range [2,3]. Phycobilins exhibit absorption in the middle of the visible spectrum (specifically the green, yellow, and orange ranges) [1,4]. In contrast to chlorophylls and carotenoids, melanin demonstrates a broad, gradually decreasing absorption spectrum that extends from the UV region into the near-infrared (IR) part of the spectrum [4].

In addition to the aforementioned pigments, flavonoids (particularly anthocyanins) constitute another significant group; these are responsible for the blue, red, and purple hues observed in flowers and fruits. Many flavonoids are also recognized as effective UV radiation absorbers, fulfilling an essential

role in the photoprotection of plants from solar radiation. This function further contributes to the lightfastness of plant-derived colourants in nature and industry, including textile applications.

This diversity in optical properties directly determines the role played by each biopigment in nature, ranging from the efficient harvesting of energy during photosynthesis to a critical function in photoprotection and the survival of organisms when exposed to light stress [2,4].

### **Photolytic mechanisms**

Four basic types of photolytic reactions are recognized:

- **Direct photolysis** – A chemical bond within the pigment is broken directly by a photon.
- **Indirect photolysis** – Another molecule is activated by a photon, which then proceeds to attack the pigment.
- **Photooxidation** – The pigment reacts with singlet oxygen.
- **Photoreduction** – Reduction processes are induced by photoexcitation.

### **Factors influencing photolysis**

- Wavelength and intensity of radiation;
- Presence of metal ions;
- Level of oxidative stress;
- Physico-chemical composition of the matrix.

## **METHODOLOGY**

This paper presents a review of contemporary relevant literature. Studies related to the photostability of chlorophylls, carotenoids, phycobilins, and melanins were collected. Classical, authoritative sources from the international scientific community are included [2-6], as is relevant domestic literature comprising textbooks and scientific articles [1]. The mechanisms of photochemical degradation and the role of pigments in photoprotection were specifically analysed.

## **FINDINGS**

### **Photolysis of chlorophylls**

Current research indicates that chlorophyll is susceptible to photoinduced degradation, which intensifies the formation of pheophytin (involving the loss of the Mg ion), chlorins, and other catabolites. UV radiation is known to significantly accelerate oxidation reactions. According to domestic studies [1], alkaline conditions further destabilize chlorophyll. These processes have been studied in detail within the context of photosynthetic biomembrane status, where the stability of both chlorophyll *a* and *b* is considered critical [6].

### **Photodegradation of carotenoids**

Carotenoids are effective scavengers of free radicals, yet they remain sensitive to strong light exposure, under which epoxides and shorter apocarotenoids are produced. Experimental work has confirmed increased degradation when exposed to high temperatures and UV sources [3]. Their role in the quenching of chlorophyll's excited state and singlet oxygen is considered fundamental for photoprotection [2,3]. The degradation of carotenoids in food products, for instance, represents a significant technological challenge [1].

### Phycobilins and melanin

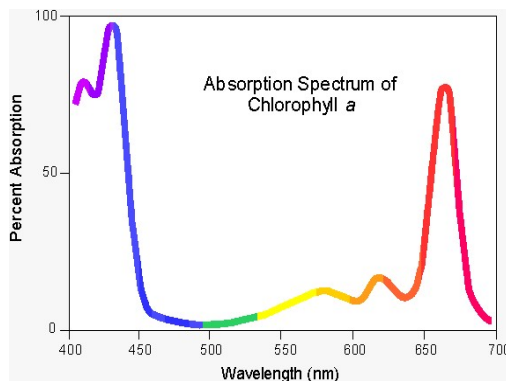
Phycobilins exhibit reduced stability in the UV range, while melanin possesses exceptional resistance and the ability to dissipate energy as heat [4]. Owing to its capacity to absorb a broad spectrum of radiation, melanin functions as an effective protective shield, thus preventing damage to surrounding tissues [4].

### DISCUSSION

Photolytic stability is observed to vary among different pigment groups. Chlorophylls are found to be the most susceptible to oxidative photodegradation, whereas melanins represent the most stable natural pigments [4]. Carotenoids possess a dual role: light is absorbed by them for photosynthesis, but they are also key to photoprotection through the quenching of excess energy [2]. By controlling environmental conditions (pH, temperature, oxygen presence), it is possible to enhance photostability, which is of particular importance for food pigments and medical photosensitizers. An understanding of the natural functions of carotenoids [3], provides insight into potential industrial applications.

*Table 1. Example of photolytic characteristics of biopigments*

Biopigment	Absorption Maximum (nm)	Light Stability	Application	Reference
Chlorophyll a	430, 662	Medium (sensitive to photo-oxidation)	Photosynthesis, bioindication	Lichtenthaler, 1987; Popović, 2005;
Carotenoids (e.g., $\beta$ -carotene)	400–500 (3 peaks)	Medium to high (matrix-dependent)	Photoprotection, antioxidant systems	Frank & Cogdell, 1996; Britton i sar., 2008;
Phycobilins	490–620 (type-dependent)	Medium (unstable in UV)	Light absorption in deeper waters	Solovchenko, 2010; Popović, 2005;
Melanin	Broad range (UV to IR)	Very high (exceptional resistance)	Photoprotection (UV screening), heat dissipation	Solovchenko, 2010;



*Figure 1: The UV/visible absorption spectrum for chlorophyll.*  
 (Source: <https://ch.ic.ac.uk/local/projects/steer/>)

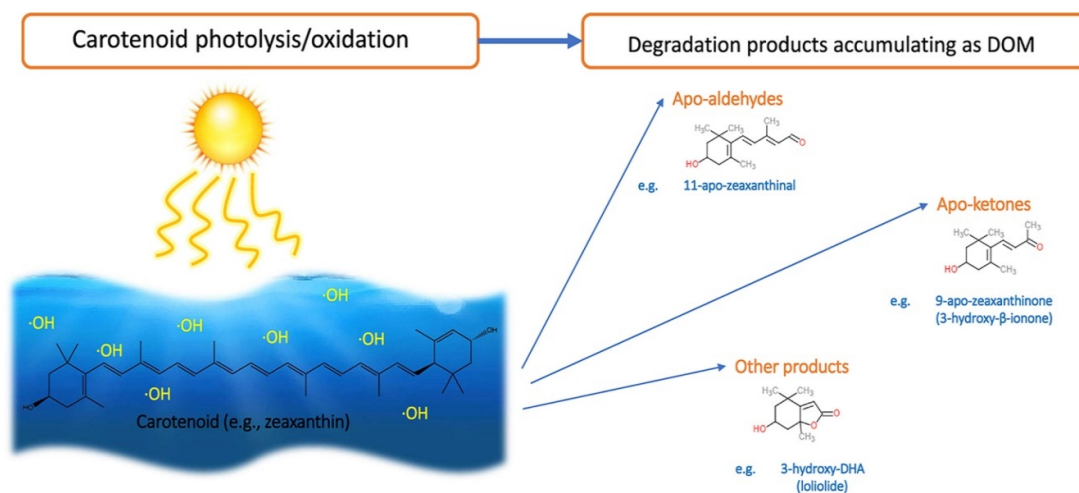


Figure 2: Degradation of carotenoids due to UV radiation (absorption changes).  
 (Source: <https://www.sciencedirect.com/science/article/abs/pii/S00456532102169X>)

## CONCLUSION

An understanding of the photolytic mechanisms of biopigments is considered crucial for applications across biotechnology, medicine, and industry [1-5]. Contemporary literature, ranging from the fundamental work of Lichtenthaler [5] to specific studies on photoprotection [4], confirms the significant impact of photooxidation on most pigments. This recognition provides opportunities for stability enhancements through chemical and technological approaches. These approaches are of vital importance for application within the textile industry, where the lightfastness of natural colourants can be significantly improved by controlling dyeing conditions and post-treatment of materials (e.g., using UV absorbers), thus enabling a broader and more sustainable use of biopigments in commercial textile production.

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## CAMBODIAN SILK

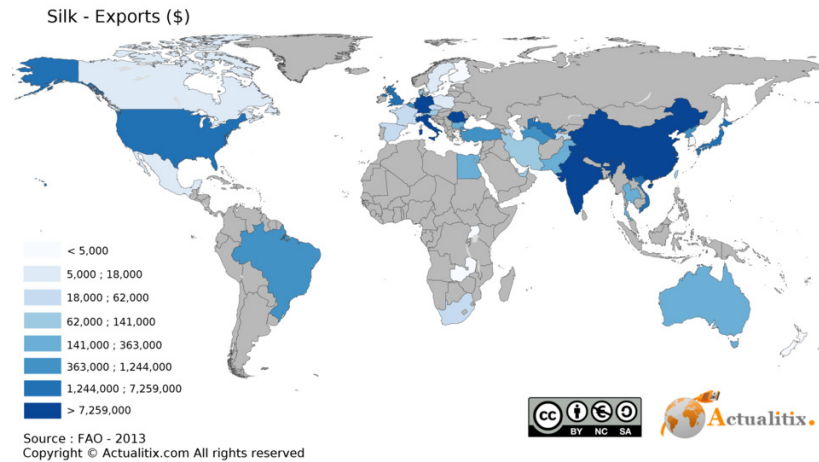
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### INTRODUCTION

Natural silk ( Silk -eng.; Soie - french.; Seide - german.; Seta -ital. ) is the second most important fiber of animal origin. It is produced as a product of the secretion of the glands of the larva of the domesticated silkworm, a butterfly from the family of moths, *Bombix mori* . The greatest industrial importance is the silk obtained from the cocoons of the domesticated silkworm . Natural silk belongs to protein fibers. According to its chemical composition, it is a protein fibroin.

The largest producers of silk in the world are Japan, China and Thailand. Sericulture in these countries is also part of their cultural heritage. In addition, China and Thailand have a large and cheap labor force. Other countries that are involved in silk production include India, Korea, Russia, Iran, Greece, Turkey, Italy, Spain and France.



*Figure 1. The world's largest silk producers*

The International Silk Association has introduced a graphic international quality mark for products made from pure natural silk. In this way, consumers are protected from imitations when purchasing items made from pure natural silk.



*Figure 2. International mark for pure silk products*

## **1. HISTORICAL DEVELOPMENT OF SILK GROWING**

The history of silkworm breeding is a combination of facts and myths. The beginning of silkworm breeding is associated with the reign of Emperor Hsang To , who ruled China between 2700 and 2600 BC. The legend of the discovery of silk is associated with the name of Princess Hsi -Ling-Shih, whom the emperor asked to investigate the cause of the destruction of the imperial mulberries. Small white worms ate mulberry leaves, and then moved to the branches where they made shiny, almost white cocoons. The princess gathered a handful of cocoons and took them to her chambers, and one accidentally fell into a cup of hot tea. She noticed that the cocoon consisted of a network of threads that resembled a spider's web. The threads were very long, she unwound them, and the cocoon became smaller and smaller. She was later proclaimed the patron saint of silkworm breeders. For almost 3000 years, the Chinese successfully kept the secret of silk and its cultivation. The death penalty was provided for revealing this secret. The Koreans kidnapped several Chinese concubines and forced them to reveal to them the method of raising silkworms and producing silk. Thus, the centuries-old secret was revealed. Later, monks from Persia smuggled silkworm eggs into Byzantium in the hollow of a bamboo stick, during the reign of Justinian I.

### **1.1. Silk Road**

The Silk Road was an ancient network of trade routes, formally established during the Han Dynasty of China. The European explorer Marco Polo traveled these routes and described them in detail in his work " Il Milione " . The Silk Road had such a profound impact on the development of world civilization that it is difficult to imagine the modern world without it.

The network was used regularly from 130 BC when the Han Dynasty officially began trade with the West until 1453 AD when the Ottoman Empire boycotted trade and closed the routes.

Chinese merchants exported silk to Western buyers. Silk fabrics were traded in Persia, Byzantium, and ancient Rome. A kilogram of purple silk fabric, at that time, was more expensive than a kilogram of gold. From Rome, and later the Christian kingdoms, wool, gold, and silver traveled east.

From Korea, the silkworm was brought to Japan and India, and later to Europe via the Byzantine Empire. Byzantium was the main producer of silk in Europe for many centuries. Cultivation was brought to North Africa by the Arabs, to Spain by the Moors, and then cultivation began in Italy. Later, cultivation spread to France, as Paris was the world center of women's fashion, which until World War II was one of the largest growers and producers of silk. With the discovery of America, silk production spread to North America, Virginia, and other provinces. Later, it began to be cultivated in South America and Australia.

The greatest value of the Silk Road was the exchange of cultures. Art, religion, philosophy, technology, language, science, architecture, and every other element of civilization were exchanged along these routes, carried by commercial goods that merchants carried from country to country. Disease also traveled along this network, as seen in the spread of the bubonic plague in 542 AD, which is believed to have reached Constantinople via the Silk Road and decimated the Byzantine Empire.

The closure of the Silk Road forced merchants to take to the sea to conduct trade, thus initiating the Age of Discovery that led to worldwide interaction and the beginning of a global community. The Silk Road served to help people understand the world they lived in. The closure of the Silk Road forced Europeans to explore and eventually conquer the New World—the Americas. Because of this, the Silk Road can be said to have laid the foundation for the development of the modern world.



Figure 3. The Silk Road

Parts of the Silk Road survive in the form of a highway connecting Pakistan and the Xinjiang Uyghur Autonomous Region of China. In the 21st century, the United Nations planned to sponsor the highway and railway. The Silk Road also inspired China's Belt and Road Initiative, a global infrastructure development strategy pioneered by President and General Secretary Xi Jinping.

### 3. CAMBODIAN SILK

#### 3.1 Introduction

Cambodia is a country in Southeast Asia with a long history of great culture and tradition. Weaving is a Khmer craft that has existed since the *Funan* period. However, some researchers have said that the Khmer could produce silk product with different decorative patterns, such as *Iboek prealeat*, *angloun* (Checked cloth), *kroma*, (scarf), *sarong sotr*, *chorabab*, *soeung*, *hol*, *phamoung*, *pidan* (used in Buddhist ceremonies) in magnificent colors, which were extracted from trees and other materials. [For a long time] people have been using these types of materials for clothes and in decorations because of their glorious natural colors. This craft [weaving] is clearly apparent on the artistic skirts of the Apsara on the walls of Angkor Wat and other temples in the wonderful territory of the Kingdom of Cambodia.

Clothes made from silk include *hol*, *phamuong*, *chorabab*, and *sarong sotr*; these traditional Khmer clothes have long been used by ordinary people, low and high-ranking officials and the king. Although today there are many modern clothes imported from foreign countries or produced locally, *hol*, *phamung*, and *chorabab* are still popular in wedding ceremonies, traditional festivals and royal ceremonies.

What are the processes of weaving and natural dyeing? In fact, it is a very hard work to weave *hol*, *phamuong*, *sarong sort*, *chorabab* to produce one skirt or one *kbin* for clothing or Khmer-style decorations for places organized to attract foreign tourists. It costs craftsmen not only money to buy the silk but also mental effort and talent. However hard it is, they work on it with diligence.

We believe that result of research on natural dyeing is vital proof to show different patterns of silk weaving and natural dyeing to all Khmer people who wish to operate business in Khmer silk products made from natural dyeing but serves as a document to preserve Khmer traditions and customs for the next generation.

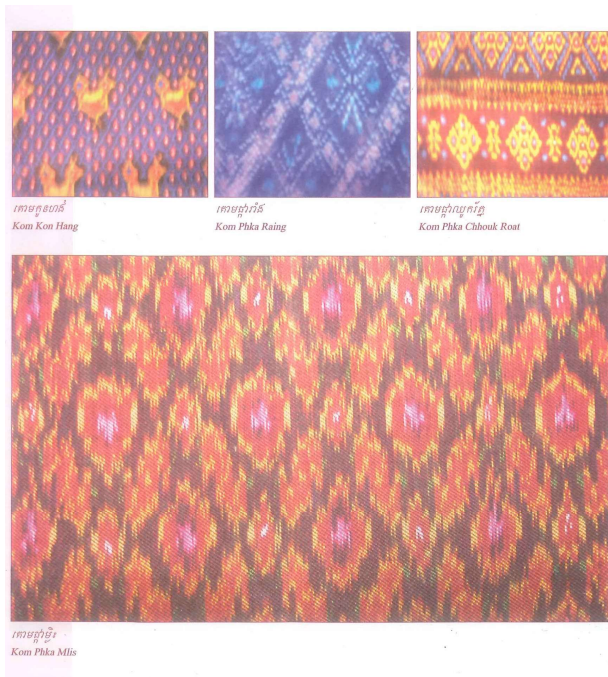
### 3.2 History of Silk in Cambodia

The silk industry started in Cambodia during the 13<sup>th</sup> century, then known as the Khmer Empire. Chinese diplomate Zhou Dagan visited the region at that time and reported the beginning of silk activities. Those developed along the Mekong and Bassac River in the south of Phnom Penh with mulberry plants to breed silk worms. The bas-reliefs of Angkor Wat and Bayon reflect these changes as Apsaras costumes display geometrical patterns similar to the Indian Ikat technique named Patola. From the 19<sup>th</sup> century until the 1970s, the weaving technique developed and the industry spread to the Tonle Sap, the largest lake in Southeast Asia, and to settlements such as Battambang and Siem Reap. As the skills had evolved, Cambodian Ikat, the dyeing technique to produce unique patterns, gained universal recognition in the 19<sup>th</sup> century. Around a quarter of families lived thanks to silk production at that time.

From the 1970's, the silk industry was disrupted under the Khmer Rouge regime which almost destroyed the industry. They strictly limited colored clothing and imposed black pajamas for the population. The Vietnamese intervention in 1979 did not benefit the silk industry which slowly recovered only after the 1993's transitional government.

### 3.3 Hol

*Keidh* is a skein of silk which weavers tie for dyeing, in English called *ikat*. Khmer weavers have their own special technique to do that. White *keidh* was first dye with red, then with yellow and lastly with blue.



To tie the *kiedh* we use young banana sheath, but today it has been replaced by nylon. There are some organizations still preserving this technique, for example the institute for Traditional Khmer Textile located in Siem Reap. According to Khmer superstition, people believe this kind of banana trees cannot be planted near their houses.

There are many patterns of *hol* in Khmer tradition, which were created by weaver from generation to generation. Through the interviews with old weavers, we found that in the past, to produce one *kben* of *hol*, they had to spend at least three months to complete the work. This takes a long because they need to feed cocoons pattern were bigger than those of today, such as *phnek Ko* (cow eyes), *klim chan*, double lines...etc.

To get a high quality of *hol*, the weaver needs to have rich experience and diligence, and take great care.

### 3.4 Phamuong

*Phamuong* is a kind of Khmer weaving product that has many colors, as required by users, but generally has only one color per piece. We remember that recently *Phamuong Kor Tea* (the color is similar to the color of a duck's neck) has been very well known.

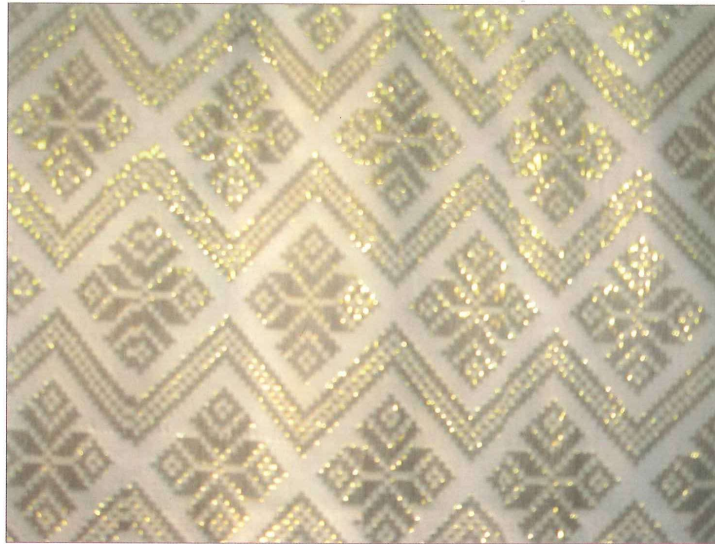
Weavers use at least three *thkor* or more if that *phamuong* has a pattern or hem decoration. In *Koh Dach*, weavers use up to 30 *thkor* for one called *phamuong tbong pich* (diamond phamuong), which has now become popular.



ចំបូលសំបុត្រក្រចក់អង្ករ  
 Hem of Phamuong, Angkor pattern

### 3.5 Chorabab

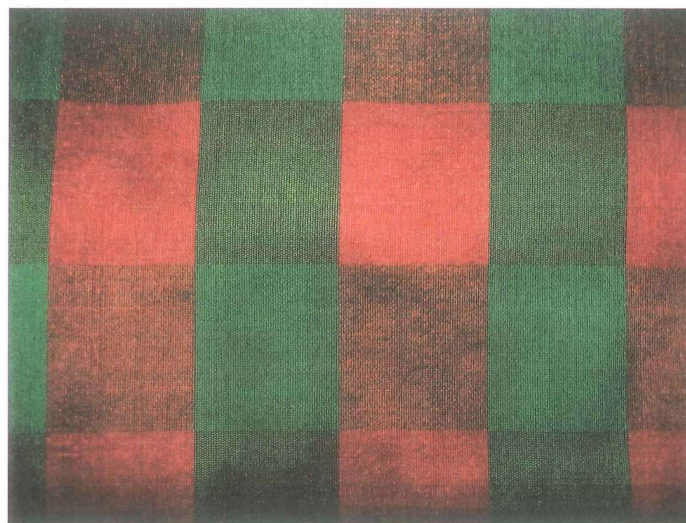
Nowadays, *chorabab* is only produced in *Khsach Kandal* district, *Kandal* province. People use *chorabab* in wedding and blessing ceremonies. The way to produce *chorabab* is similar to how to make *hol* and *phamuong*. There is a kind of cloth similar pattern such as *kantout* flower, *chan* flower, and diamond. There is a kind of cloth similar to *Chorabab* called *lboek*. *Lboek* is different from *chorabab* because *chorabab* use *sesoy* to show up the pattern or flowers, but *lboek* uses silk instead. Weavers use a lot of *thkor* to produce *chorabab*; in some case they use sixty *thkor*.



បរាប្រាណ៍  
 Corabab Phka Chan

### 3.6 Sarong Sotr

Khmer *Muslim* likes to use and wear it not only at home but also in big ceremonies. The pattern of sarong is not complicated and has a few models like *dom ach cvea*, which is quite well-known and *sarong sotr*.



គោម ដូរពេលវេលា សារន៍ មកពីព្រែកចន្ទ្រាន  
 Kom Dom Ach Jvea from Prek Changkran

### 3.7 Scarf

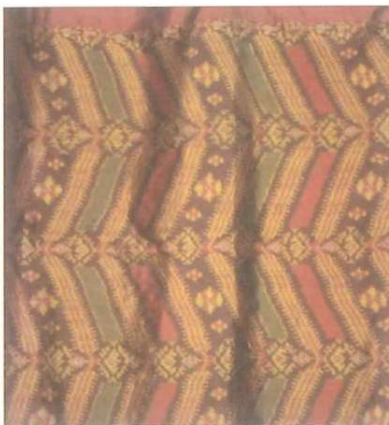
Every person has at least one scarf (*krama*). We mostly use scarves made from cotton and cotton-silk (more expensive). It is a part of Khmer tradition.



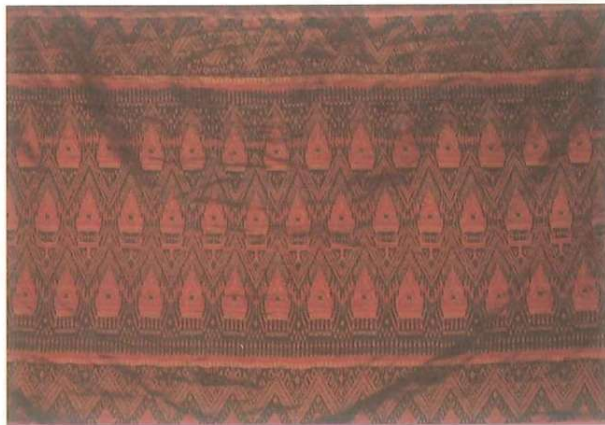
### 3.8 Pidan and Roneang

This is used only in Buddhist ceremonies. The pattern on *pidan* illustrates the life of Buddha, nature, flowers, animals and Apsara.

The way to produce *pidan* or *roneang* is almost the same as the way we make *hol* because the silk has to be tied and dyed. It is currently only produced in *Bati* district, Takeo province.



ពិដានមារូបនាគមកពីខេត្តសៀមរាប  
 Picture of naga from Siem Reap



ពិដានូបប្រាសាទនេះមានដាក់គំនិតនៅអង្គការគាំពារកុមារខ្មែរខេត្តតាកែវ  
 Pidan at CYK, Bati district, Takeo province



*ពិរាតនិយាយអំពីការចេញទៅបួសរបស់ព្រះពុទ្ធនេះមានដាក់គំនិតនៅអង្គការតំណែរកុមារខ្មែរ ខេត្តតាកែវ*  
 Pidán at CYK, Bati district, Takeo province

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## COMPUTER PROGRAMS IN THE FUNCTION OF CLOTHING PRODUCTION DEVELOPMENT

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### ABSTRACT

*The paper emphasizes the application of software and research priorities in the mass production of clothing/fashion, which go towards the realization of the "smart factory" project. To that end, research is focused on three units: production technology, production management and customer/service interaction. Within the production technology development is focused on flexible systems for the production of small series as well as on the development of technologies for direct 3D production. Within that, the priorities are directed towards: the availability of flexible systems for the production of small batches of clothing with high economic justification; trend - production of clothes in a 3D environment with 3D equipment; product development/innovation, which implies the application of virtual textile materials for simulation and prediction of production possibilities; greater accessibility and application of virtual textile materials; better accessibility of knowledge about the production of textile materials. All this today requires, to an ever greater extent, the application of existing computer programs in the production of clothing and the development of new ones.*

**Keywords:** computer programs for clothing production, CAD software for clothing construction and fitting of cut images, production tracking program

### 1. INTRODUCTION

The paper emphasizes the application of software and research priorities in the mass production of clothing/fashion, which go towards the realization of the "smart factory" project. To that end, research is focused on three units: production technology, production management and customer/service interaction. [1-2]

Within the production technology development is focused on flexible systems for the production of small series as well as on the development of technologies for direct 3D production. Within that, priorities will also be directed towards:

- ❖ the availability of flexible systems for the production of small batches of clothing with high economic justification,
- ❖ trending - clothing production in a 3D environment with 3D equipment,
- ❖ product development/innovation, which includes the application of virtual textile materials for simulation and prediction of production possibilities,
- ❖ greater accessibility and application of virtual textile materials,
- ❖ better accessibility of knowledge about the production of textile materials.

Within production management, development is aimed at:

- ❖ simulation,
- ❖ optimization,
- ❖ flexibility,

- ❖ virtualization of production processes,
- ❖ reorganization of the production process,
- ❖ supply chain as well as on
- ❖ introduction of conceptual and technological improvements.

Within the customer/service iteration, development is focused on:

- ❖ process virtualization,
- ❖ scanner application, interactive clothing design that includes a realistic simulation of each individual customer in selected or specially designed clothing. [1-2]

The vision of the development of the textile and clothing industry increasingly requires the application of existing computer programs in the production of clothing and the development of new ones. Today, the need to use computers in all segments of the textile and clothing industry does not need to be explained, because computers successfully help solve a large number of problems that are most often faced by clothing manufacturers today. The answer to these problems mainly consists in the development of new production strategies. These strategies set completely new and very strict organizational and production conditions for the clothing industry. These conditions are reflected in the preparation of the production process in a very short period of time, as well as in the adaptation of production lines, machines, equipment and personnel for sudden and rapid changes. In this way, production preparation and production of technological documentation represent a significant factor in the aforementioned strategies. For these tasks, computer programs are used to a large extent for the creation of technological documentation, monitoring and analysis of production.

## **2. CIM CONCEPT IN THE CLOTHING INDUSTRY**

The process of creating clothing and textile products is a complex process. In it, raw materials, basic and auxiliary materials are processed to create a clothing or textile product [3]. The industrial way of producing clothes and textiles represents a very complex system of organization: people, time, machines, production space, organization, materials, etc. All these problems are solved by a special service called technical preparation of production. Technical preparation of production, e.g. clothes consists of a large number of experts in the field of ready-made technology distributed in four organizational units: structural preparation, technological preparation, operational preparation and material testing.

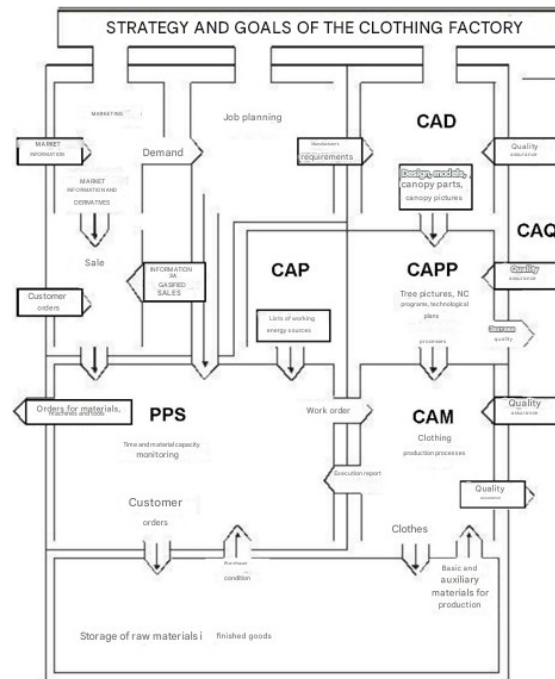


Figure 1: Strategy and goals of a clothing manufacturing company

The warehouse of raw materials, tailoring, tailoring, finishing and warehouse of finished products represent a unique and functional area of the production system where the routes of transportation of materials, i.e. semi-finished products and finished products, are organized in the most rational way. This rationalization also included the application of computers, which led to the development of the CIM concept in this industry. Figure 1 shows the strategy and goals of the clothing factory based on this concept. [3]

Indirect and direct connection with the production process enables the use of the same data, transformation and creation of new data, as well as direct communication between multiple computer systems of different purposes. This concept of interconnected different computer systems is called the CIM concept.

The labels in Figure 1 are:

CAD - computer integrated design, production of models, cutting parts and cutting images,

CAP - computer-integrated list of parts and energy sources,

CAPP – computer unified data for cutting images, NC programs and plans of technological operations,

PPS - computerized monitoring of capacities, time and materials,

CAM - computer-integrated clothing production process i

CAQ - computer unified monitoring of product quality.

The challenges faced by the textile and clothing industry are mainly: satisfying new generations of consumers, protecting margins in a highly competitive environment, increasing the number of collections, developing new business models, etc. Figure 2 shows these challenges.



Figure 2: Challenges faced by the textile and clothing industry [4]

## 2.1. CAD - COMPUTER UNIFIED DESIGN, CREATION OF MODELS AND CUTTING DRAWINGS

Today, it is difficult to comprehensively present all the places of application of computers in the field of design, model making and cutting images. If we looked at the most important thing that led to big changes in clothing companies in the world and in our country, we could start from the first step in the realization of a garment, which is the creation, selection and development of ideas.

### 2.1.1. USE OF COMPUTER IN GATHERING IDEAS FOR A NEW PRODUCT

For a long time, designers at this stage had the freedom to create. It was very important for the designers to create original ideas that would result in garments acceptable to an increasingly discerning market. However, since a few years ago, there have been visible changes in these jobs made possible by the use of computers, through which global databases on fashion trends can be accessed in a very simple and fast way. Namely, large global companies, as well as a large number of companies in Serbia that have their own brand, use databases for these tasks, such as e.g. WGSN. [5] The WGSN database is a global trend analysis and research service that provides creative and business intelligence in apparel, style, design and retail at least two years in advance and for some information up to five years in advance. Using the WGSN database increases the speed of product launch on the market, productivity and efficiency of the supply chain.

Also, the travel costs of fashion designers to fashion shows and fairs are reduced. The database provides insight into a large data archive that has millions of images and hundreds of thousands of pages of information, fashion shows of the world's most famous designers, as well as information on identified and documented trends around the world. The database contains current achievements and changes in the world of fashion, art and culture, color, current consumer behavior, current materials, the latest developments in the world of business in the field of fashion and technology.

### 2.1.2. COMPUTER PROGRAMS FOR CREATING A FASHION COLLECTION U ELECTRONIC FORM

Today on the market there are a large number of CAD solutions for creating fashion collections. The creation of the collection aims to concretize the market's demands on a group of certain clothing items of the same purpose. Software solutions enable fashion designers to find new trends and topics more easily, they enable easier designing of new styles, creation of products of various colors and materials. The ability to obtain high-quality images enables easy and quick communication with readers of technical specifications.

One of the most significant possibilities offered by new technologies when creating a collection is the creation of an electronic catalog of products. These catalogs can also be created in the appropriate software, without the need to sew clothing samples beforehand. So you can create a virtual product catalog that is offered to customers. Depending on the requirements of the customers, who were offered a virtual catalog, the procurement of materials and production is approached. In this way, a really large number of clothing models can be produced simply and cheaply in a very short time. It is also important that the catalog is in electronic form and as such can be easily sent via the Internet to customers. [6]

### 2.1.3. COMPUTER PROGRAMS FOR TECHNICAL PREPARATION OF TEXTILE MATERIALS IN ELECTRONIC FORM

Large global companies, manufacturers of CAD/CAM software and equipment in the fashion industry, offer software for electronic preparation of technical documentation for textile materials: fabrics, knitwear and printed materials. These softwares allow easy access and use of interweaving materials, color palettes, combining yarns according to raw material composition and fineness, as well as virtual presentation of finished materials made in these softwares. Preparation in these softwares also enables the actual production of these materials on the machines of major global manufacturers. Namely, this technical preparation is compatible with software for managing the production of fabrics, knitwear, printed materials, on looms, knitting machines, etc. [7-10]

### 2.1.5. CONSTRUCTION OF BASIC CUTS

The construction of basic clothing cuts implies the creation of a technical drawing on which the main and auxiliary lines and cutting points are constructed, modeled, completed and duplicated. A large number of software solutions are used for these jobs today. Mostly all these solutions have the following basic functions: creation of tailoring parts, using functions for basic construction; entering cutting parts (templates) using the digitization function; developed tools for creating: eyelets, pleats, seams, advanced techniques; measurements, pleats, symmetrical (mirrored) opening of cuts; quick and easy modification of existing tailoring parts, etc. Figure 4 shows the layout of the working windows of today's most common manufacturers of this type of software solutions in Serbia: Lectra and Gemini.

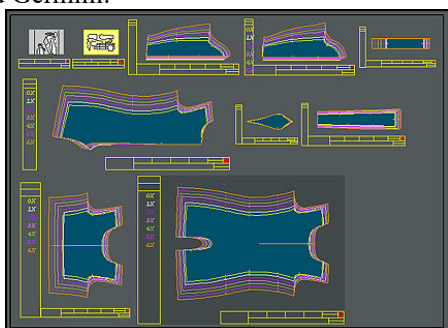


Figure 4.a): Display of duplicated cutting parts

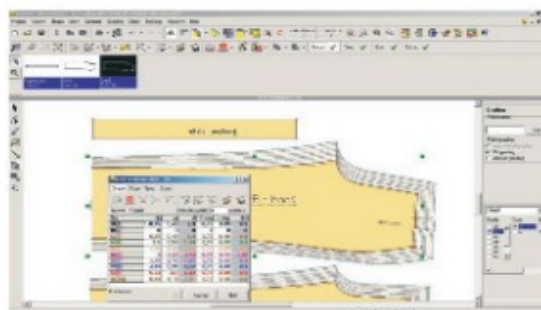


Figure 4.b): Display of duplicated cutting parts in

in the software of the French manufacturer  
 Lectra Figure

the software of the Romanian manufacturer  
 Germini

The benefits of using Lectra's 2D modaris software are: two-way connection between cuts and measurements, solution for patterned fabrics, user configuration, unique grading solution, automated cut preparation tools, integrated market best practices, etc. All these advantages result in time savings of around 30% for collection development. The benefits of using Lectra's 2D modaris software are shown in Figure 5.

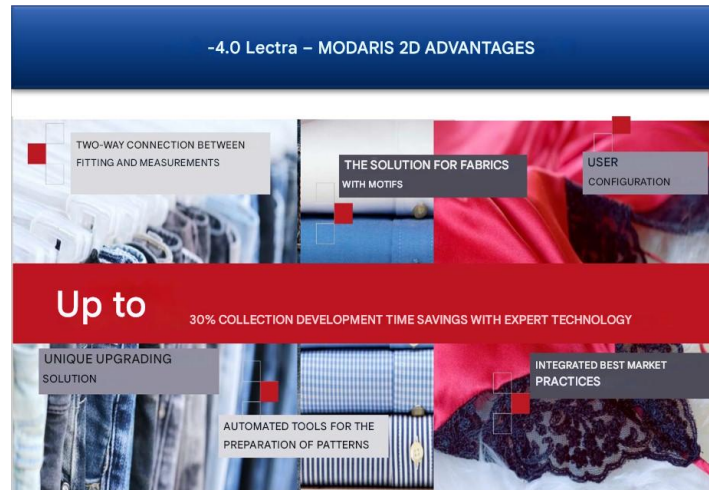


Figure 5: Benefits of using Lectra's 2D modaris software [4]

### 2.1.6. CREATION OF CUTTING IMAGES

The cutting image is a set of all the necessary cutting parts of a garment, made of the same material (eg basic) that are rationally fitted on one surface (paper, fabric, screen...). When fitting tailoring parts, today all software solutions are generally guided by the following fitting rules: creation of a clear tailoring image, so that tailoring can proceed smoothly; placement of the template must be exactly according to the marked direction of the base of the fabric or the row of loops of the knit; fitting according to a certain pattern, if the cut image is made for patterned materials (checked, striped, printed, etc.) and achieving the most rational position, which affects the determination of material consumption norms.

Figure 6 shows the appearance of the working windows of today's most common manufacturers of this type of software solutions in Serbia: Lectra and Germini.

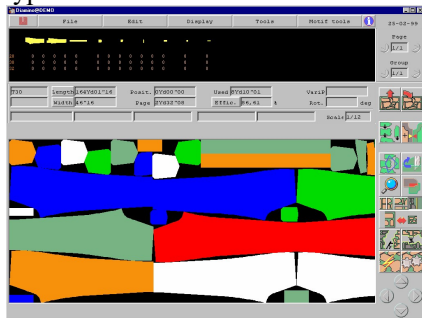


Figure 6.a): View of the cutting image in the software of the French manufacturer Lectra

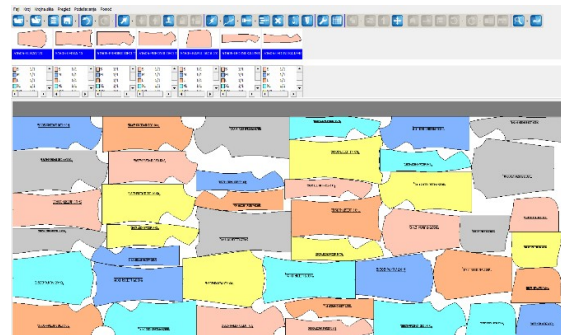


Figure 6.b): Display of the cut image in the software of the Romanian manufacturer Germini

### 3. CONCLUSION

The main obstacle to the introduction of CAD/CAM solutions in clothing production is large financial investments. If you look at the equipment of Serbian manufacturers of men's and women's clothing, you can see that they are mainly equipped with CAD systems. Recently, the fact that more and more of our companies are purchasing cheap CAD solutions that are on the market up to three times cheaper than the solutions of the world's well-known manufacturers of this equipment is visible. However, large manufacturers of modern CAD/CAM solutions offer the possibility of obtaining production data that greatly enable production management to make rational decisions that can significantly reduce production costs.

Real decisions are made mainly on the basis of data on the so-called "hidden time" in production that is difficult to see without the analysis information of the production process offered by CAD/CAM solutions.

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## PROTECTION AND COMFORT PROPERTIES OF FACE MASKS

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### ABSTRACT

Recent outbreak of the COVID-19 pandemic, which started in January 2020, has dramatically changed the world, posing fundamental challenges to our healthcare and economic system, but also to cultural and social life. This pandemic made us to realize that, despite the enormous advances in pharmaceuticals and medical science, in the first moments, which are essential in the containment of spreading of any pandemic, the important role is played by the non-pharmaceutical measures for protection. So, the cloth masks, usually made from cotton yarn, were used as personal protective equipment (PPE) beside the other measures, since they provide a physical barrier in the prevention of spreading the respiratory virus droplets. They weren't subject to regulation, but still, they should have appropriate wearable characteristics, filtration efficiency and breathability.

In this paper, the results obtained from the performed analysis on several fabrics and medical masks such as weight per unit area, air permeability, water vapor permeability and their correlation. The results show that the cotton masks have higher air permeability than nonwoven masks, while water vapor permeability is similar for all mask types.

**Key words:** face masks, coronavirus, air permeability, water vapor permeability,

### INTRODUCTION

The coronavirus disease was declared as PHEIC- Public Health Emergency of International concern on 30 January 2020 by WHO- World Health Organization (WHO, 2020), and as pandemic disease on 11 March 2020 (WHO, 2020).

Similarly, to other viruses, the SARS-CoV-2, is mainly transmissible through respiratory droplets [Morawska, L., 2006; Mittalet R. et al., 2020] and physical contact (Yang, P., 2020). So, the primary measures of protection against COVID-19, which proved to be effective in reducing virus spread (Abajo, F. et al., 2020), are limited to physical distancing, improved hygiene, reduced traveling and wearing of personal protective equipment, especially for occupational groups at risk of COVID-19 (Liu, C. et al., 2020; Ahmed, S. et al., 2020; Shoenfeld, Y., 2020; Wu, S., 2020; Hoen, E., 2020).

As a measure for prevention, facemasks were identified as an essential physical barrier for people to protect themselves as well as others, from aerosols containing coronavirus. They can be especially important for asymptomatic people and those with mild symptoms (Leung, N. et al., 2020), so they are one of the suggested preventive measures for reducing the transmission rate of COVID-19.

So, during outbreaks, their use was either mandatory or highly recommended, both in professional and social contexts (Roberta L. et al., 2022). Specifically, in the current COVID-19 pandemic, more than 50 countries have since made masks obligatory in public areas (Liang P., 2020).

Also, the cloth mask was popularized with the CDC's recommendation to wear masks in public during the pandemic. The previous information shared with the public was that these masks should be constructed of two or more layers of washable, breathable cloth, in addition to other specifications. The cloth masks were considered less protective if they are not made with at least two layers, are not worn appropriately, are not washed frequently, and/or are not adequately sealed around the face (Deena A. et al., 2022).

It is important that the mask components do not interact with the normal breathing process and maintain a state of thermophysiological comfort in the facial region (Gericke, A. et al., 2021).

According MK CWA 17553:2020 standard (SIR, 2020): Community face coverings – Guide to minimum, methods of testing and use requirements, there are several requirements addressing the use of the masks for self-protection. More important are fabric breathability and the ability to absorb moisture to prevent condensation from falling on the user, biocompatibility of the material etc. Regarding fabric requirements, the standard recommends the use of tightly constructed fabrics, masks assembled of 2 or 3 fabric layers, the use of soft and supple fabrics for masks and washing ability at minimum 60°C.

Various types of masks are used by healthcare workers and the general worldwide population, like cloth masks, medical masks and respirators (MacIntyre, C. et al., 2015). However, only medical masks and respirators are subject to regulation.

Usually, the masks are made up of a multi-layered structure, with non-woven fabric layers made of melt-blown polymer, most commonly polypropylene (PP), but also polystyrene (PS), polycarbonate (PC), polyethylene (PE), or polyester (PES). Spunbond and meltblown fabrics can be used as the middle layer, since this layer has the highest filtration efficiency (Dacicj A. et al., 2020). While spunbond fabrics consist of coarser filaments with greater tensile strength and smaller pressure drop, the meltblown fabric contains smaller diameter fibers, with submicrometer dimensions, and improved filtration efficiency. Also, the meltblown process permits the development of filaments with a large diameter variation compared to spunbonded (Mao, N., 2016).

In past years, the outcome from the enormous research in the field of material, surface, and aerosol science and engineering (Huang, H. et al., 2020), have enriched the textile materials with appropriate properties (like improved filtration, better wearable characteristics, antibacterial and antiviral activity, breathability, etc.), which are essential for successful prevention of the spread of viruses.

This reality was placing textiles on the front line in the fight against the COVID-19 pandemic and since many textile organizations had implemented the production of fabric protective masks and protective clothing, the textile industry became an important participant in the health protection (NT, 2020).

The fabric masks can be produced via knitting, weaving and nonwoven production techniques, and the production technique directly affects the mask performance (Akalin M. et al., 2010). In terms of airborne droplet filtration and air permeability the nonwoven fabrics outperform than woven and knitted fabrics (Chellamani K. et al., 2013).

There is no doubt that, efficient filtration efficiency and air permeability are important requirements, but also the design and selection of the material components that determine the level of wear comfort should be prioritized. Thus, the paper investigates the protection and comfort properties of various types of facemasks for personal protection.

## EXPERIMENTAL PART

### Fabric-mask samples

Six samples of masks were subject for analysis. The technical features and appearance of the investigated masks are shown in table 1, and fig 1.

*Table 1. The technical characteristics of the face masks*

Designation	G1	G2	G3	G4	Medical mask	KN95 mask
Fibre composition	Cotton	Cotton	Cotton	Cotton	PP/PE	PP/PE
Textile structure	Woven	Woven+ knit	Woven	Woven	Nonwoven	Nonwoven
Layers	1	2	2	2	3	4
Areal density, g/m <sup>2</sup>	210.2	265.4	233.8	316.2	88.2	160



Figure 1: The investigated masks

The masks from G1 to G4 are masks sewn from cotton fabric, having woven or knitted structure. The mask G5 is medical mask and G6 is KN95 mask made of nonwoven structure of PP and PE composition. Regarding the number of layers, only the first mask G1 consists of one woven layer, while the rest (G2, G3 and G4) have two layers. The samples G3 and G4 are made from woven fabric, and the composition of sample 2 is combination of external woven and internal knitted cloth. The medical mask, is composed of three layers: inner and outer layers of non-woven fabric and the middle layer of melt-blown fabric, fig. 2 (Alp K. et al., 2022).

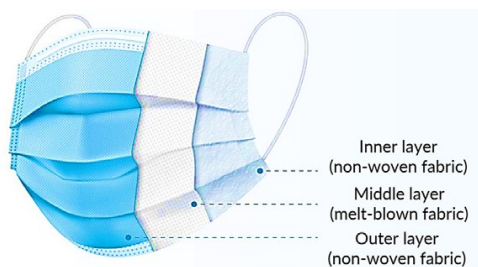


Figure 2: The layer structure of medical mask

The structure of KN95, consisting of 4 layers 1 is presented in fig. 3. The properties of all particular layer were separately analyzed.



Figure 3: The layer structure of KN 95 mask

**Used methods, aparatus and standards**

In this study, following characteristics of the masks and layers were tested: mass per unit area, air permeability and water vapor permeability. The masks were tested for air permeability using ISO

9237:1995 standard, at pressure of 100Pa and testing sample area of 20 cm<sup>2</sup>. SDL ATLAS MO21A air permeability tester was used, fig. 4.



Figure 4: SDL ATLAS MO21A air permeability tester

The analysis for water vapor permeability were performed based on the standard BS 7209:1990 and the results are presented in unit of g/m<sup>2</sup>/day, calculated by the appropriate equation. For this analysis SDL ATLAS M261 water vapor permeability tester was used, figure 5.



Figure 5: SDL ATLAS M261 water vapour permeability tester

The mass per unit area was determined using the standard test method D 3776-96.

## RESULTS AND DISCUSSION

The features of the investigated masks depicted in Table 1, show that cotton fabric masks have higher weight ranging from 210 to 316 g/m<sup>2</sup>, while nonwoven masks are lighter having fabric weight from 88 to 160 g/m<sup>2</sup>. Also, the cotton fabric masks have 1 or 2 layers, while nonwoven masks have 3 or 4 layers.

The important features of fabric masks are filtration efficiency and fabric breathability. Regarding breathability, MK CWA 17553:2020 standard requires air permeability of fabric to be greater or equal to 96 l/s/m<sup>2</sup>, at vacuum pressure of 100Pa. All tested mask samples have values above this value and are therefore appropriate for personal protection. The results of air permeability are shown on Figure 6. All cotton masks, with the exception of G3, have higher air permeability compared to nonwoven medical masks, which means that they are more comfortable for breathing than nonwoven one.

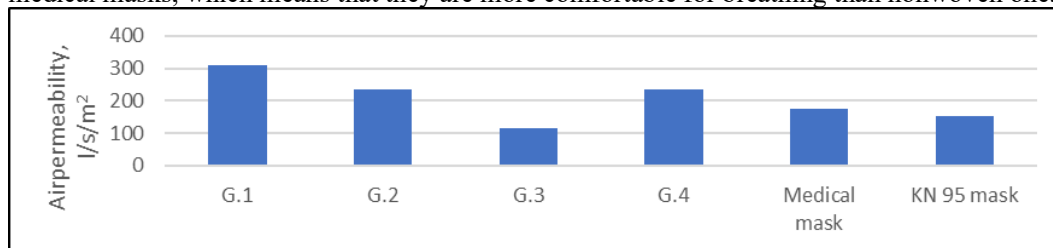
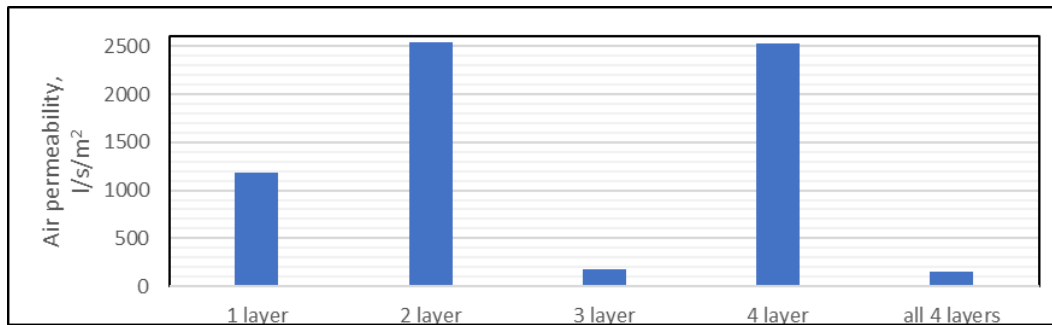


Figure 6: Air permeability of the investigated masks

The air permeability of the KN95 mask is investigated separately for all 4 layers and it is shown on figure 7. There is great difference in air permeability from layer to layer. Actually, the third layer has lowest air permeability value and determines the air permeability of the whole mask: The air permeability of the third layer is 175 l/s/m<sup>2</sup>, while the total air permeability of the mask is 152 l/s/m<sup>2</sup>.



*Figure 7: Air permeability of the KN95 face mask by individual layers*

Regarding wearer comfort, it is considered that water vapour permeability of the masks is an important for thermal comfort (Ka-Po, L. et. Al., 2020). The higher rate of permeability increases comfort of the wearer because it keeps the mask dry. The values of water vapor permeability testing are displayed in table 2. The values are similar for various mask samples and indicate that all investigated masks provide similar wearer comfort. In addition, there is no correlation between air permeability and water vapor permeability of the samples.

*Table 2. Water vapor permeability of the face masks*

Sample	G.1	G.2	G.3	G.4	Medical mask
WVP (g/m <sup>2</sup> /day)	560	558	553	560	562
I (%)	94	96	95	96	97

## CONCLUSION

In this study, the characteristics: mass per unit area, air permeability and water vapour permeability of face masks were investigated. The findings are following:

- the fabric cotton masks are heavier ranging from 210 to 316 g/m<sup>2</sup>, while nonwoven masks are lighter with weight from 88 to 160 g/m<sup>2</sup> and more comfortable to wear regarding fabric weight.
- the air permeability of all fabric masks, medical and KN 95 mask had values above the recommended value by MK CWA 17553:2020 standard, which suggest are appropriate for personal protection offering acceptable breathing features. However, the air permeability of the majority of cotton masks is higher than nonwoven mask, which points to greater breathing comfort of cotton masks.
- the air permeability of the separately tested 4 layers of KN 95 mask is with great difference from layer to layer. The third layer has lowest air permeability value and obviously determines the air permeability of the whole mask.
- regarding the wearing comfort, the results for water vapor permeability indicates similar features for all tested samples.

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## **CIRCULAR ECONOMY IN THE SERVICE OF SUSTAINABLE FASHION**

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### **ABSTRACT**

This paper explores the possibilities of applying the principles of the circular economy in the textile and fashion industry, one of the largest global consumers of resources and polluters of the environment. Starting from a theoretical framework, the practices of reuse, recycling, redesign and product life cycle extension are analyzed, considering the impact of fast fashion, technological innovation and regulatory frameworks. The results indicate that circular models have the potential to significantly reduce the ecological footprint through innovative business models, as well as the application of digital solutions. Obstacles to the application of the circular economy in the textile and fashion industry have been identified in the form of low consumer awareness, resistance to higher prices and the dominance of linear business models. The paper concludes that the successful implementation of circular principles requires the synergy of industry, consumers and institutions, as well as a strategic approach based on education, transparency and cooperation of all participants in the value chain. The proposed guidelines emphasize the importance of innovation, regulatory support and education as key levers for the sustainable transformation of the fashion industry.

**Key words:** circular economy, fashion industry, sustainable development

### **INTRODUCTION**

The circular economy represents an alternative to the linear model of the economy, which is based on the "take-make-use-throw" way of thinking. It is a model based on the principles of eliminating waste and pollution, keeping materials in use as long as possible, and restoring natural systems (Upadhayay et al., 2024). The circular economy is achieved by designing and creating products in such a way as to maximize their lifespan, but also by maintaining, servicing and recycling. The key characteristic of the circular economy is that it leads to the concept of "zero percent waste" and that the biggest changes occur in the design of products and packaging (European Parliament, n.d.). The principles of the circular economy are the redesign, i.e. the reuse of products, the division of products into possible ingredients, each of which can be further used, the use of renewable energy sources, as well as the motivation of users with various incentives to return the packaging that goes through the reprocessing process. The goals of the circular economy are based on saving raw resources, saving energy, protecting the environment and creating green jobs (Yang et al., 2022).

On the other hand, the textile industry is one of the biggest polluters of the environment at the global level. Huge amounts of water, chemicals and energy are used to produce textiles, while most discarded clothing ends up in landfills or incinerated (Gluvakov et al., 2024). The concept of fast fashion, which is rooted globally, further deepens this problem, as changing trends and low prices encourage mass consumption and short-term use of clothing (Maiti, 2025). Apart from the environmental aspect, the industry also faces social challenges, such as poor working conditions and insufficiently transparent supply chains, which makes this area one of the key areas for the implementation of sustainable practices.

In accordance with the above, connecting the principles of the circular economy and the textile industry is extremely important for future generations. The introduction of circular models in the fashion sector not only reduces negative environmental impacts, but also opens up opportunities for innovation in design, new business models such as rental, resale and redesign, improvement of waste management and consumer education (Gray et al., 2025). This paper aims to show how the circular economy can contribute to the sustainable development of the fashion industry and to provide an overview of current studies and models that can serve as a basis for further progress in this area.

## **METHODOLOGY**

### **Problem and subject of research**

The textile and fashion industry produces large amounts of waste, consumes significant natural resources and contributes to environmental pollution. Although initiatives to reduce negative impact through sustainable practices have become more frequent in recent years, their implementation still does not provide sufficiently effective results. The main problem is reflected in the insufficient application of circular economy principles in this industry, both at the level of design and production, as well as in consumer behavior and waste management.

The subject of the research is an analysis of the possibility of applying the circular economy in the fashion industry, with a focus on researching the potential for reducing the ecological footprint and creating innovative business solutions that connect sustainability and competitiveness in the fashion sector.

### **Research goal**

The goal of this research is to determine, by reviewing the relevant literature, how the principles of the circular economy can be connected with the textile and fashion industry. By analyzing previous research and examples of good practice, the work aims to identify key challenges and opportunities for the integration of circular models in this sector, as well as to provide guidelines for the improvement of existing practices.

### **Research question**

Based on analyzed theories and studies, we will try to answer the following question:

RQ1: How can the principles of the circular economy be applied in the textile and fashion industry?

### **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 circular economy represents an approach that integrates the economy and the waste management system, and is based on a design that excludes the negative consequences of economic activities. In the circular economy, the focus is on activities that preserve value in the form of energy, materials and labor, and an important principle of this concept is the protection and improvement of natural systems, using renewable resources. By applying the principles of the circular economy, companies from various industries, including the textile and fashion industries, transform their business into a socially

responsible one, which implies activities that fulfill ethical obligations towards all interest groups, including consumers, competitors and third parties (The Circular Economy in Detail, 2019).

The textile and fashion industry represent one of the important areas of development of circular economy business models, both at the global level and in the domestic economy. The application of the circular economy in the production and use of textiles implies the reuse of clothing, i.e. the development of the slow fashion movement, the production of items for everyday use from collected materials, the production of insulating material and the use of textile waste for the production of new fabrics. Literature analysis indicates that circular economy initiatives in the fashion industry are recognized as necessary, but their implementation still faces significant challenges (Schumacher & Forster, 2022; Farrukh & Sajjad, 2024; Jenkins, 2025). Although there are numerous drivers for the introduction of circular models, such as the increasing environmental awareness of consumers, innovative business models and regulatory changes, the dominance of fast fashion is not sufficiently followed by consumer awareness, and the market structures of existing inefficient practices are still strong (De Aguiar Hugo et al., 2021). Therefore, when it comes to circular economy drivers in the textile and fashion industry, they include consumer awareness of circular fashion, but also institutional and market initiatives that encourage innovation and green business practices (Abdelmeguid et al., 2025). However, significant challenges that are present are the low level of awareness among the wider population, the resistance of consumers to accept a higher price, as well as business models oriented to low price and short-term consumption (Jimenez-Fernandez et al., 2023; Biyada & Urbonavičius, 2025).

Contemporary research also emphasizes the importance of technological solutions in enabling circular practices. For example, AI-powered automation of textile sorting through robots, spectroscopy and classification can significantly improve waste sorting efficiency and increase recycling capability (Spyridis et al., 2024; Carvalho et al., 2025). Technology can contribute to transparency, monitoring of value chains and the development of digital solutions such as digital product passports, which promote circularity and create long-term sustainability (Gazzola et al., 2025). The application of circular economy practices in the real sector shows certain results. Namely, regulations such as extended producer responsibility (EPR) are being introduced in the EU, which require brands to finance the collection and recycling of textiles, and certain brands use wardrobe rental systems to close the loop and reduce waste (Client Challenge, n.d.). So, in practice there are good business examples, as well as an institutional framework for a circular economy in the textile industry, and the further development of similar initiatives can solve the problem of the lack of available recycled raw materials and overproduction.

Textile reuse has a significantly greater environmental benefit than recycling, and every ton of textile waste that is reused can save enormous amounts of energy and resources. These effects show that extending the life cycle of clothing through sharing, repairing and reselling has a greater environmental significance than recycling itself (Abrishami et al., 2024). In parallel with that, it is important to highlight the encouragement of users to participate in the circular economy by educating, informing and applying the principles of green marketing and sustainable development (Enabling Consumer Choices for a Circular Economy, 2022). By encouraging users to sustainable consumption and the slow fashion movement, it can significantly contribute to the implementation of the circular economy in this area, create socially responsible business and care for the wider social community (Gluvakov et al., 2022).

The results show that circular models in the fashion industry have enormous potential for reducing the ecological footprint and improving sustainability, especially through the synergy of technology, proper policies, and changes in consumer behavior. Permanent and systemic integration of these models requires collective engagement, from design and production, through legislative incentives, to consumer education. In addition to the identified benefits and challenges, the results indicate the need

for a strategic approach that integrates all participants in the value chain, namely designers and manufacturers, as well as retailers and consumers (Ritch et al., 2023; Abdelmeguid et al., 2024). The importance of education, process standardization and support through public policies and financial instruments is particularly emphasized. In the next chapter, concrete guidelines and recommendations for practice will be presented, including the development of digital tools for product tracking, innovative business models based on reuse and repair, as well as measures to strengthen consumer awareness and encourage responsible consumption, in order to adopt circular models and create a foundation for the transformation of the fashion industry.

## **GUIDELINES AND RECOMMENDATIONS**

Based on analyzed theory, the following guidelines and recommendations for improving sustainable management in the textile industry are provided:

- Brands and producers should develop strategies that extend the use of clothing through redesign, repair, resale and rental, which will significantly reduce the need for new resources, reduce waste and offer consumers value through innovative services.
- The introduction of digital solutions and systems for tracking the origin of materials can ensure greater transparency of the supply chain and facilitate recycling. Technological innovations can enable more efficient sorting and processing of textile waste and encourage the responsibility of all participants.
- Educating consumers about the importance of sustainable consumption and the value of circular fashion is key to changing behavior. Through campaigns, workshops and green marketing messages, it is possible to increase awareness and motivation for responsible purchasing and return of used products.
- It is necessary to support and expand regulations such as extended producer responsibility, subsidies for innovative green technologies and standardization of recycling processes. An active role of the state and industry associations can accelerate the adoption of circular models and reduce market resistance.
- Sustainable transformation of the fashion industry requires the joint engagement of designers, manufacturers, retailers and end users. Developing partnerships and initiatives that connect all participants allows creating closed cycles, reducing waste and opening new market opportunities.

## **CONCLUSION**

The circular economy offers significant opportunities for the transformation of the fashion and textile industry, which is one of the largest consumers of resources and polluters of the environment. The analysis carried out in this paper shows that the introduction of circular principles such as extending the life cycle of products, reuse and repair, as well as the development of new business models and digital solutions can significantly reduce the ecological footprint and open space for innovation. The work shows that there are positive examples in practice and good regulatory changes, but that it is still necessary to change consumer awareness and stop the market dominance of fast fashion and resistance to higher prices of sustainable products. By applying the proposed guidelines, greater transparency, more efficient use of resources and the creation of closed value cycles can be achieved. In this way, the competitiveness of the industry is improved, but it also contributes to the preservation of the environment and social responsibility. This paper confirms that the integration of circular models is an important step towards a sustainable future of the fashion industry and represents an investment in long-term development and prosperity.

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## **TEXTILE EDUCATION AND INDUSTRIAL DEVELOPMENT IN PAKISTAN**

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### **Abstract**

*Pakistan's textile and apparel sector remains the backbone of its industrial economy, export earnings, and employment generation. While the sector's role in cotton cultivation, spinning, weaving, processing, and garment manufacturing is widely acknowledged, the contribution of textile education to sustaining and upgrading this ecosystem has received comparatively limited scholarly attention. This paper examines the evolution, structure, and strategic importance of textile education in Pakistan within the broader context of global value chains, technological transformation, and sustainability imperatives. It argues that textile education has played and must continue to play a pivotal role in enhancing productivity, innovation, and international competitiveness. By tracing the historical development of textile education, assessing its alignment with industry needs, and evaluating international collaboration and future challenges, the study positions textile education as a critical driver of Pakistan's long-term industrial resilience and export diversification.*

**Keywords:** Textile education, Pakistan textile industry, cotton value chain, industrial development, exports, skills development, global value chains

### **1. Introduction**

Textiles have historically formed the industrial and economic backbone of Pakistan. Since independence, the sector has evolved from a largely agrarian, cotton-based economy into one of the world's major textile and apparel producers. Today, Pakistan ranks among the leading global suppliers of yarn, fabrics, home textiles, and apparel, serving markets across Asia, Europe, and North America.

Despite this centrality, the sustainability and competitiveness of the textile sector increasingly depend not only on natural endowments or cost advantages but also on human capital, technological capability, and institutional strength. Textile education—spanning engineering, design, management, and applied sciences—has therefore emerged as a strategic pillar in Pakistan's industrial development.

This paper explores textile education in Pakistan as an enabling system that links agriculture, manufacturing, exports, and innovation. It situates textile education within the full cotton-to-clothing value chain and evaluates its contribution to productivity, employment quality, and global integration.

### **2. The Strategic Significance of the Textile Sector in Pakistan**

#### *2.1 Cotton Cultivation and Agricultural Linkages*

Pakistan is among the world's largest cotton-producing countries, with cotton serving as a foundational raw material for the textile industry. Millions of farmers depend directly or indirectly on cotton cultivation, particularly in Punjab and Sindh. The crop supports rural livelihoods, contributes to agricultural GDP, and feeds a vast industrial network.

The interdependence between cotton quality and industrial output underscores the importance of technical knowledge—not only in farming practices but also in fiber testing, contamination control, and quality standardization. This linkage highlights the need for trained professionals who understand both agricultural inputs and industrial requirements.

### *2.2 Integrated Textile Value Chain*

Pakistan possesses a rare advantage among developing economies: a nearly complete textile value chain, encompassing:

#### **Cotton ginning**

- Spinning (yarn production)
- Weaving and knitting
- Dyeing, printing, and finishing
- Garment manufacturing and made-ups
- Branding and export marketing

This vertical integration allows value addition at multiple stages, reduces reliance on imports, and creates employment across skill levels. However, each stage requires specialized technical expertise, process optimization, and quality assurance—functions heavily reliant on educated and trained human resources.

### *2.3 Contribution to Exports and GDP*

The textile and apparel sector accounts for over half of Pakistan's total merchandise exports, making it the country's largest foreign exchange earner. It contributes significantly to manufacturing GDP and industrial output, while also serving as a buffer against external economic shocks.

Beyond export revenues, the sector supports upstream industries such as chemicals, packaging, logistics, energy, and machinery, creating multiplier effects across the economy.

### *2.4 Employment and Social Impact*

The textile industry is Pakistan's largest industrial employer, providing jobs to millions of workers, including a substantial proportion of women. Employment spans rural and urban areas, formal and informal segments, and skilled and semi-skilled occupations.

Improving job quality, productivity, and workplace standards depends on managerial competence, technical supervision, and innovation—areas directly influenced by the strength of textile education and training institutions.

## **3. Evolution of Textile Education in Pakistan**

### *3.1 Early Foundations*

Textile education in Pakistan began as a response to post-independence industrialization needs. Early institutions focused on practical training in spinning and weaving to support the emerging mill sector. Over time, diploma programs evolved into degree-level education as industry complexity increased.

The establishment of dedicated textile institutes and university departments marked a shift from craft-based learning to engineering-oriented and scientific education, incorporating mathematics, physics, chemistry, and mechanical processes.

### *3.2 Institutional Expansion and Diversification*

Over the past few decades, textile education in Pakistan has expanded significantly, with public and private universities offering undergraduate, postgraduate, and doctoral programs in:

- Textile Engineering
- Fiber and Polymer Science
- Garment Manufacturing
- Textile Chemistry and Processing
- Fashion and Apparel Design
- Textile Management and Merchandising

This diversification reflects the growing sophistication of the industry and the need for interdisciplinary skills that combine technology, design, sustainability, and business acumen.

### *3.3 Alignment with Industrial Needs*

A defining feature of textile education in Pakistan has been its close relationship with industry. Many curricula are developed in consultation with textile mills, export houses, and trade bodies. Internship programs, industrial training semesters, and joint research initiatives have helped bridge theory and practice.

Graduates often enter the workforce with hands-on exposure to production environments, quality control systems, and export compliance requirements—an advantage in a highly competitive global market.

## **4. Textile Education as a Driver of Competitiveness**

### *4.1 Productivity and Process Innovation*

Educated textile professionals contribute directly to productivity improvements through better machine utilization, waste reduction, energy efficiency, and process optimization. Engineering knowledge enables firms to adopt modern machinery and integrate automation where feasible.

In a sector facing rising input costs and energy constraints, such efficiency gains are essential for maintaining international competitiveness.

### *4.2 Quality Assurance and Compliance*

Global buyers increasingly demand compliance with international standards related to quality, safety, labor practices, and environmental performance. Textile education equips professionals with knowledge of testing protocols, certification systems, and regulatory frameworks.

This capability has enabled Pakistani exporters to retain access to demanding markets and to move toward higher-value segments such as branded apparel and technical textiles.

### *4.3 Research and Development Capacity*

- Universities and research centers play a growing role in applied textile research, including:
  - Development of blended and functional fabrics
  - Sustainable dyeing and finishing techniques
  - Wastewater treatment and recycling
  - Performance and technical textiles

Although R&D investment remains modest compared to advanced economies, textile education institutions form the nucleus of innovation potential.

## **5. Global Recognition and International Collaboration**

### *5.1 International Standing of Pakistani Graduates*

Graduates of Pakistan's textile programs are employed across the Middle East, Europe, East Asia, and Africa. Their presence in multinational firms and international supply chains reflects the global recognition of Pakistan's textile engineering and management education. Many professionals have also pursued advanced studies abroad, contributing to knowledge transfer and professional networking.

### *5.2 Academic and Industrial Partnerships*

Pakistani textile institutions increasingly collaborate with foreign universities, research centers, and development agencies. These partnerships include:

- Faculty and student exchange programs
- Joint research projects
- Curriculum benchmarking with international standards
- Industry-sponsored laboratories and training centers

Such engagement helps align Pakistan's textile education with global technological and sustainability trends.

### *5.3 Role in South–South Cooperation*

Pakistan's experience in textile education also positions it as a knowledge partner for other developing countries seeking to build textile industries. Training programs and technical assistance initiatives have contributed to regional and South–South cooperation.

## **6. Emerging Challenges and Opportunities**

### *6.1 Technological Transformation*

Digitalization, automation, and data-driven manufacturing are reshaping global textiles. Pakistani textile education must adapt by incorporating:

- Smart manufacturing concepts
- Industry 4.0 applications
- Digital design and simulation tools
- Supply chain analytics

Keeping pace with technological change is essential to avoid being locked into low-value segments.

### *6.2 Sustainability and Environmental Responsibility*

Environmental compliance is no longer optional in global textile markets. Education programs increasingly emphasize:

- Sustainable fiber sourcing
- Cleaner production methods
- Circular economy models
- Environmental management systems

Textile education thus plays a critical role in aligning industrial growth with environmental stewardship.

### *6.3 Bridging Academia–Industry Gaps*

While collaboration exists, gaps remain between academic research and industrial application. Strengthening applied research, industry-funded projects, and commercialization mechanisms will enhance the impact of textile education.

## **7. Policy Implications and Future Directions**

A coherent national strategy linking textile education with industrial policy can amplify economic outcomes. Key priorities include:

- Investment in modern laboratories and faculty development
- Incentives for university–industry research collaboration
- Integration of sustainability and digital skills into curricula
- Expansion of postgraduate and doctoral research capacity
- Such measures would reinforce Pakistan’s position in global textile value chains while improving employment quality and export resilience.

### **Textile Education Institutions in Pakistan: A Comprehensive Landscape**

Pakistan’s textile and apparel sector—the backbone of its industrial economy—demands a strong, diversified, and forward-looking education ecosystem. Over the decades, Pakistan has developed a multi-layered textile education infrastructure, ranging from engineering universities and design schools to vocational institutes and policy-oriented research bodies. Together, these institutions support the entire textile value chain, from cotton and fiber science to apparel manufacturing, fashion design, exports, and innovation.

This compilation presents a comprehensive list of textile-related educational and research institutions in Pakistan, categorized by academic focus and functional role. It reflects the country’s commitment to human capital development in one of its most strategic sectors.

#### ***I. Universities and Degree-Granting Institutions***

##### **A. Dedicated Textile Universities and Specialized Institutes**

###### ***National Textile University (NTU), Faisalabad***

Pakistan’s flagship textile university, offering undergraduate, graduate, and doctoral programs in Textile Engineering, Textile Technology, Clothing and Textile Management, Polymer Engineering, and Applied Sciences. NTU enjoys strong industry linkages and international collaborations.

###### ***Textile Institute of Pakistan (TIP), Karachi***

A specialized institution focusing on Textile Science, Apparel Manufacturing, Textile Design, Fashion Design Management, and Textile Marketing. TIP bridges technology, design, and business.

###### ***College of Textile Engineering, Bahauddin Zakariya University (BZU), Multan***

Offers BS and postgraduate programs in Textile Engineering and Textile Design, serving South Punjab’s industrial and agricultural base.

##### **B. Engineering Universities with Textile Programs**

###### ***NED University of Engineering and Technology, Karachi***

One of Pakistan’s oldest engineering institutions, offering advanced programs in Textile Sciences and Engineering, including MS and PhD research.

###### ***University of Engineering and Technology (UET), Lahore – Faisalabad Campus***

Provides undergraduate and postgraduate education in Textile and Materials Engineering with strong industrial exposure.

###### ***Mehran University of Engineering and Technology (MUET), Jamshoro***

Offers BE, ME, and PhD programs in Textile Engineering, serving Sindh's textile and cotton belt.

*Balochistan University of Information Technology, Engineering and Management Sciences (BUITEMS), Quetta*

Offers Textile Engineering and Fashion & Textile Design, contributing to human resource development in Balochistan.

**C. Agricultural and Applied Science Universities**

*University of Agriculture, Faisalabad (UAF)* – Department of Fibre and Textile Technology  
 Focuses on fiber science, yarn manufacturing, fabric development, wet processing, and garments, linking agriculture with industrial processing.

*University of the Punjab* – Institute of Polymer and Textile Engineering, Lahore

Provides interdisciplinary education and research in polymers, textiles, and advanced materials.

**II. Design, Fashion, and Creative Institutions (Textile-Related)**

*Pakistan Institute of Fashion and Design (PIFD), Lahore*

A premier institute specializing in Textile Design, Fashion Design, and Fashion Marketing, with strong global exposure.

*Indus Valley School of Art and Architecture (IVS), Karachi*

Offers Textile Design and Fashion Design programs emphasizing creativity, sustainability, and cultural heritage.

*Beaconhouse National University (BNU), Lahore*

Integrates textile and fiber studies within its visual arts and design programs.

*University of Sargodha – College of Textile and Fashion Design*

Provides degree and diploma programs in Textile and Fashion Design.

*Asian Institute of Fashion Design (AIFD), Iqra University, Karachi*

Focuses on apparel, fashion, textile design, and merchandising.

*Hunerkada College of Visual and Performing Arts (Islamabad and Lahore)*

Offers hands-on education in textile crafts, weaving, surface design, and embellishment.

*Lahore School of Fashion Design (LSFD)*

Known for programs in Textile Design and Fashion Design with industry relevance.

*University of South Asia, Lahore*

Offers fashion and textile-related programs integrated with creative industries.

**III. Technical and Vocational Institutions**

*Government College of Technology, Faisalabad*

Provides Diploma of Associate Engineering (DAE) programs in Textile Dyeing, Printing, and related technologies.

*Pakistan Readymade Garments Technical Training Institute (PRGTI)*

A key skill-development institute for garment manufacturing, apparel production, and industrial stitching.

*Provincial Vocational Training Institutes (VTIs)*

Operate across Pakistan, offering short courses in garment stitching, textile processing, and basic industrial skills.

**IV. Research, Training, and Policy Support Institutions**

*National Textile Research Centre (NTRC), Faisalabad*

Conducts applied research, product testing, innovation, and industry-oriented development in collaboration with academia and exporters.

*Export Promotion Bureau (EPB) / Trade Development Authority of Pakistan (TDAP)*

Supports textile export research, market intelligence, trade promotion, and policy coordination.

*Pakistan Central Cotton Committee (PCCC) and Technological Research Sub-Committees*

Focus on cotton research, fiber quality improvement, and technological advancement for the textile value chain.

Pakistan's textile education ecosystem reflects the breadth and depth of its textile industry, spanning engineering, agriculture, design, vocational skills, and policy research. This diversified structure enables the country to support its textile value chain from cotton fields to global fashion markets.

Strengthening coordination among these institutions, expanding international collaboration, and aligning curricula with emerging technologies—such as technical textiles, sustainability, and digital manufacturing—will further enhance Pakistan's competitiveness in the global textile economy.

### **Conclusion**

Textile education in Pakistan is not merely an academic enterprise; it is a strategic national asset deeply embedded in the country's economic, social, and industrial fabric. From cotton fields to global retail shelves, educated professionals sustain the systems that generate exports, employment, and innovation.

As global competition intensifies and sustainability expectations rise, the future of Pakistan's textile sector will increasingly depend on the quality, relevance, and adaptability of its textile education ecosystem. Strengthening this foundation offers a pathway toward higher value addition, technological upgrading, and inclusive industrial growth—ensuring that textiles remain a cornerstone of Pakistan's development in the decades ahead.

## **MACHINE VISION IN THE TEXTILE INDUSTRY: A COMPREHENSIVE REVIEW OF APPLICATIONS, METHODS, AND CHALLENGES**

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### **ABSTRACT**

Machine vision has become an essential technology in the textile industry due to the growing need for improved product quality, higher production efficiency, and increased automation aligned with the principles of Industry 4.0. Conventional manual inspection processes are slow, subjective, and unsuitable for today’s high-speed textile manufacturing. Machine vision systems enable contactless, objective, and real-time inspection, making it possible to accurately identify fabric defects, dimensional irregularities, and color inconsistencies. This paper provides an in-depth overview of machine vision applications in textiles, with particular attention to fabric defect detection, yarn and fiber evaluation, color and pattern inspection, and seam quality assessment. In addition, widely used image processing techniques, machine learning methods, and deep learning approaches are examined and compared. Major challenges such as material variability, lighting conditions, real-time performance requirements, and the lack of labeled datasets are also discussed. Finally, emerging trends and future research directions are outlined, emphasizing the integration of artificial intelligence, the Internet of Things, and smart manufacturing technologies.

**Keywords:** machine vision, textile industry, fabric inspection, defect detection, image processing, deep learning, industry 4.0

### **INTRODUCTION**

The textile industry is undergoing a significant transformation driven by rapid advances in automation, digitalization, and artificial intelligence [1]. As global competition intensifies and customer expectations regarding product quality become increasingly stringent, textile manufacturers are under constant pressure to improve production efficiency while maintaining consistent quality standards [2], [3]. Quality inspection represents a critical stage in textile manufacturing, as defects such as holes, stains, misweaves, and color inconsistencies can significantly reduce the commercial value of textile products [4], [5].

Traditionally, quality control in the textile industry has relied heavily on manual inspection performed by trained operators [2]. Although human inspectors are capable of identifying a wide range of defects, manual inspection is inherently subjective, labor-intensive, and prone to fatigue-related errors, particularly in high-speed production environments [4], [6]. Studies have shown that the effectiveness of manual inspection decreases significantly over extended working periods, leading to inconsistent defect detection rates [2], [7].

Machine vision systems have emerged as a promising solution to overcome the limitations of manual inspection. By integrating imaging hardware with advanced image processing and pattern recognition algorithms, machine vision enables automated, objective, and repeatable inspection of textile materials [8], [9]. These systems can operate continuously at high speeds and provide real-time feedback to production lines, contributing to reduced waste, improved productivity, and enhanced product quality [10], [11].

In recent years, the adoption of machine vision in the textile industry has been further accelerated by advances in machine learning and deep learning techniques [12], [13]. Convolutional neural networks (CNNs) and other data-driven approaches have demonstrated remarkable performance in complex visual inspection tasks, including the detection of subtle and irregular textile defects [14]–[16]. Consequently, machine vision has become a core component of smart textile manufacturing and Industry 4.0 frameworks [1], [17].

This paper presents a comprehensive review of machine vision technologies applied in the textile industry. The main objectives are to analyze current applications, review commonly used algorithms and methods, discuss existing challenges, and highlight emerging trends and future research directions. The remainder of the paper is organized as follows: Section II introduces the fundamentals of machine vision systems, Section III reviews key applications in textile manufacturing, Section IV discusses algorithms and techniques, Section V outlines challenges and limitations, and Section VI presents future perspectives and concluding remarks.

## **II FUNDAMENTALS OF MACHINE VISION SYSTEMS**

A machine vision system is an integrated combination of hardware and software components designed to acquire, process, and analyze images for automated inspection and decision-making purposes. In the textile industry, machine vision systems are primarily employed for real-time quality control and defect detection due to their non-contact and objective nature [8].

### **-System Components**

A typical machine vision system consists of several key components, including an image acquisition device (camera), illumination source, optical system (lenses), image processing unit, and decision-making software [9]. The performance of the entire system strongly depends on the appropriate selection and integration of these components, particularly in textile applications where surface textures and material properties vary significantly.

### **-Imaging Devices**

Cameras play a central role in machine vision systems. In textile inspection, commonly used imaging devices include charge-coupled device (CCD) and complementary metal–oxide–semiconductor (CMOS) cameras [18]. CCD cameras have traditionally been favored for their low noise and high image quality, whereas CMOS cameras have gained popularity due to higher frame rates, lower power consumption, and reduced cost.

Depending on the application, line-scan or area-scan cameras may be employed. Line-scan cameras are particularly suitable for continuous textile production lines, as they capture images one line at a time and reconstruct high-resolution images of moving fabrics [19]. Area-scan cameras, in contrast, are more commonly used for stationary inspection tasks or smaller textile samples.

### **-Illumination Techniques**

Proper illumination is a critical factor in the success of machine vision systems for textile inspection. Due to complex surface structures, varying reflectance properties, and differences in fabric color, inadequate lighting can result in poor contrast and unreliable defect detection [20]. Common illumination techniques include front lighting, backlighting, diffuse lighting, and structured lighting.

Backlighting is often used to detect holes, tears, and dimensional defects, as it enhances the contrast between the fabric and the background [21]. Diffuse lighting helps reduce shadows and specular reflections, making it suitable for textured and patterned fabrics.

#### **-Image Acquisition and Preprocessing**

Once images are captured, preprocessing steps are applied to enhance image quality and reduce noise. Common preprocessing techniques include grayscale conversion, filtering, histogram equalization, and contrast enhancement [22]. These steps are essential for improving the robustness and accuracy of subsequent defect detection and classification algorithms.

In textile applications, preprocessing is particularly important due to uneven illumination, fabric deformation, and motion-induced artifacts. Effective preprocessing enables the extraction of relevant features while minimizing the influence of irrelevant background information [10].

### **III MACHINE VISION APPLICATIONS IN THE TEXTILE INDUSTRY**

Machine vision has been widely adopted across various stages of textile manufacturing due to its ability to provide fast, objective, and repeatable inspection results. The most significant applications include fabric defect detection, yarn and fiber inspection, color and pattern analysis, and seam and stitching inspection [2].

#### **-Fabric Defect Detection**

Fabric defect detection represents the most extensively researched and industrially applied use of machine vision in the textile industry. Common fabric defects include holes, stains, broken ends, misweaves, slubs, and color variations, all of which can significantly affect fabric quality and market value [4].

Early machine vision systems for fabric inspection relied primarily on traditional image processing techniques, such as thresholding, edge detection, and morphological operations [5]. To address limitations associated with complex textures, statistical and frequency-domain methods, including gray-level co-occurrence matrices (GLCM), Fourier transform, and wavelet-based techniques, have been introduced [7].

In recent years, deep learning-based approaches, particularly convolutional neural networks (CNNs), have demonstrated superior performance in fabric defect detection tasks [14]. As a result, deep learning has become the dominant approach in state-of-the-art fabric inspection systems [15].

#### **-Yarn and Fiber Inspection**

Machine vision is extensively used for yarn and fiber inspection to monitor parameters such as diameter uniformity, hairiness, twist level, and surface defects [23]. Vision-based yarn inspection systems typically employ high-resolution cameras combined with controlled illumination to extract

geometric and texture features [24]. Compared to traditional mechanical sensors, machine vision provides a non-contact measurement approach with higher accuracy and reduced risk of material damage [25].

#### **-Color and Pattern Inspection**

Color consistency and pattern accuracy are critical quality attributes in textile products. Machine vision systems are used to detect color deviations, misprints, and pattern misalignments during production [26]. Color inspection systems often operate in RGB, HSV, or CIELAB color spaces to improve perceptual uniformity [27] and may integrate spectrophotometric data to further enhance measurement accuracy [28].

#### **-Seam and Stitching Inspection**

In garment manufacturing, machine vision is applied to seam and stitching inspection to detect defects such as skipped stitches, seam puckering, and misalignment [29]. Image processing and pattern recognition techniques are commonly used for this purpose [30], while recent studies have demonstrated the effectiveness of deep learning-based approaches in improving robustness under varying fabric types and lighting conditions [31].

### **IV ALGORITHMS AND METHODS FOR TEXTILE MACHINE VISION**

The performance of machine vision systems in the textile industry largely depends on the selection of appropriate algorithms for image analysis and decision-making. Over the years, these methods have evolved from traditional image processing techniques to advanced machine learning and deep learning-based approaches [32].

#### **-Traditional Image Processing Techniques**

Traditional image processing methods typically involve image preprocessing, feature extraction, and rule-based classification [33]. Texture analysis techniques, such as gray-level co-occurrence matrices (GLCM) and local binary patterns (LBP), as well as frequency-domain methods including Fourier and wavelet transforms, are widely used to characterize fabric textures and detect defects [34], [35]. However, these approaches are often sensitive to noise, illumination variations, and parameter settings, which limits their generalization capability [36].

#### **-Machine Learning-Based Methods**

To overcome the limitations of rule-based approaches, machine learning techniques have been introduced for textile inspection tasks. These methods use handcrafted features extracted from images in combination with classifiers such as support vector machines (SVM), k-nearest neighbors (k-NN), decision trees, and artificial neural networks (ANN) [37]. Machine learning-based approaches offer improved adaptability and classification accuracy compared to traditional methods [38], but their performance strongly depends on feature quality and the availability of representative training data [13].

#### **-Deep Learning Approaches**

Deep learning has significantly advanced textile machine vision by enabling end-to-end learning directly from image data. Convolutional neural networks (CNNs) are the most widely used deep learning models for textile inspection tasks, including defect detection, classification, and

segmentation [15], [16]. Advanced architectures such as fully convolutional networks (FCNs) and U-Net enable pixel-level defect localization and real-time inspection performance [39]. Despite their superior accuracy, deep learning-based approaches require large labeled datasets and substantial computational resources, which can limit their deployment in small- and medium-sized textile enterprises [40].

## **V CHALLENGES AND LIMITATIONS**

Despite significant progress, the implementation of machine vision systems in the textile industry still faces several challenges and limitations. One major challenge arises from the high variability of textile materials, including differences in fabric structure, yarn density, color, texture, and finishing processes [6]. This variability makes it difficult to design robust inspection systems that generalize across different product types.

Illumination conditions represent another critical challenge. Variations in lighting intensity, direction, and color temperature can significantly affect image quality and defect visibility, particularly for textured or reflective fabrics [41]. Consequently, careful illumination design and adaptive lighting strategies are essential for reliable inspection performance [42].

Real-time processing requirements pose additional constraints, especially in high-speed textile production lines. Machine vision systems must process large volumes of image data within strict time limits to avoid production bottlenecks [11]. While traditional image processing methods are computationally efficient, advanced deep learning-based approaches often require powerful hardware accelerators, such as GPUs, to achieve real-time performance [43].

Another major limitation is the limited availability of labeled datasets for training and evaluating machine learning and deep learning models. Acquiring and annotating textile defect images is time-consuming and costly, particularly for rare defect types [44]. This issue often leads to class imbalance and limited model generalization, motivating research into data augmentation, transfer learning, and semi-supervised learning approaches [45].

## **VI FUTURE TRENDS AND RESEARCH DIRECTIONS**

The future of machine vision in the textile industry is closely linked to the broader development of smart manufacturing and Industry 4.0. One emerging trend is the integration of machine vision systems with the Internet of Things (IoT) and cyber-physical systems, enabling real-time monitoring, data sharing, and adaptive process control [1].

Artificial intelligence-driven inspection systems are expected to play a central role in next-generation textile factories. Advances in deep learning architectures, self-learning systems, and explainable artificial intelligence (XAI) are likely to improve the robustness, transparency, and trustworthiness of automated inspection solutions [17]. In addition, the increasing adoption of edge computing is gaining attention as a means of reducing latency and bandwidth requirements by processing image data closer to the production line [45].

Sustainability considerations are also shaping future research directions. Machine vision systems can contribute to sustainable textile production by reducing material waste, minimizing rework, and improving resource efficiency through early defect detection [3]. As environmental regulations become more stringent, the role of automated quality control in supporting sustainable manufacturing practices is expected to continue to grow.

## CONCLUSION

Machine vision has become an indispensable technology in the modern textile industry, providing effective solutions to the limitations of traditional manual inspection methods. As textile production increasingly moves toward automation and digitalization within the Industry 4.0 paradigm, machine vision systems play a crucial role in ensuring high product quality, production efficiency, and process reliability. This paper has presented a comprehensive review of machine vision applications in the textile industry, covering system fundamentals, key application areas, commonly used algorithms, existing challenges, emerging trends, and future research directions.

The review demonstrates that machine vision has been successfully applied to a wide range of textile inspection tasks, including fabric defect detection, yarn and fiber inspection, color and pattern analysis, as well as seam and stitching evaluation. Moreover, machine vision enables objective, non-contact, and real-time inspection of textile products, significantly outperforming traditional manual inspection methods in terms of consistency, speed, and reliability. While early approaches relied on conventional image processing techniques and handcrafted features, recent advances in machine learning and deep learning—particularly convolutional neural networks—have substantially improved detection accuracy and robustness. These data-driven methods have shown strong potential for handling subtle, irregular, and highly variable textile defects that are difficult to detect using conventional techniques.

Looking ahead, the integration of machine vision with artificial intelligence, the Internet of Things, and smart manufacturing systems is expected to further enhance automated textile inspection capabilities. Emerging trends such as edge computing, explainable artificial intelligence, and sustainability-driven quality control are likely to shape future research and industrial applications. Overall, machine vision will remain a key enabling technology for achieving intelligent, efficient, and sustainable textile manufacturing in the years to come.

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## **TEXTILE WASTE MANAGEMENT AND MATERIAL INNOVATION: A NEW PERSPECTIVE**

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### **ABSTRACT**

This review paper synthesizes research on textile waste management, sustainability, and innovative reuse of textile materials, with a focus on the Republic of North Macedonia. Over the past fifteen years, studies have examined the generation, classification, and treatment of textile waste, revealing its environmental and economic implications. The analyses cover pre-consumer, post-consumer, and industrial waste, providing valuable insights into their composition and management practices. Findings indicate that pre-consumer cutting waste dominates in the Macedonian apparel industry, primarily consisting of cotton and cotton-blend fabrics. Although up to 95% of this waste could be recycled, most still ends up in landfills due to inadequate infrastructure, limited resources, and weak regulations. Comparative research highlights the gap between local and European circular economy practices.

Recent investigations have developed new methods for quantifying waste and explored converting textile waste into sustainable insulation materials. These innovations reduce landfill dependence and create new eco-market opportunities. Overall, the research illustrates a shift from disposal toward resource valorization and circularity, reinforcing the importance of innovation, education, and public-private collaboration for a more sustainable textile industry.

**Keywords:** textile waste, sustainability, recycling, circular economy, insulation materials.

### **INTRODUCTION**

The global textile industry has become one of the fastest-growing sectors, yet it remains a major source of environmental pollution due to waste generation, chemical usage, and unsustainable production models. In the context of the Republic of North Macedonia, where the apparel industry is a vital economic sector, the problem of textile waste management is particularly pronounced.

Textile waste is classified into three groups (Maksimov S. et al., 2022):

- Textile waste generated before use (*pre-consumer*) - it represents the waste of the production which occurs in the processing of fibres while forming yarns, fabrics, knitted and non-wovens, textile products, including residues when cutting the materials (pattern waste, damaged fabrics and end-of-rolls wastes),
- Textile waste generated after use (*post-consumer*) - it represents all types of clothing or textiles for households which has no longer usability value for consumers and is thrown away, regardless of whether it is poured, damaged, superficially or simply out of fashion trends,
- *Industrial textile waste* - the waste generated from textile manufacture for commercial or industrial purposes, including textile waste from the manufacturing of carpets and curtains and hospital waste.

Managing such waste is a complex issue largely determined by the production technologies in use. Since entirely waste-free production technologies do not yet exist, the re-utilization of post-industrial waste must be regarded as a fundamental concept in textile waste management. The accumulation of textile waste results in a loss of resources and energy, creates environmental challenges, and leads to

additional expenses for collection, transport, and disposal. Although contemporary waste management systems consider landfilling the least desirable option, it continues to dominate textile waste management practices.

## **1. COMPREHENSIVE REVIEW OF RESEARCH ON TEXTILE WASTE AND SUSTAINABILITY**

The focus of this paper will be on studies related to the situation of textile waste, its quantity and quality, and its management in the Republic of North Macedonia, as well as on textile waste management practices in other countries.

### **1.1. Quantity and quality of textile waste in the Republic of North Macedonia**

Over the past fifteen years, several studies have emerged on pre-consumer textile waste and its management in the Republic of North Macedonia. The initial phase of these studies are focused on identifying and classifying the textile waste in R. N. Macedonia. The studies classified textile waste into pre-consumer and post-consumer categories, with emphasis on pre-consumer waste such as cutting scraps, selvedge waste, and defective materials. Early studies (Jordeva et al., 2013; 2014) provided one of the first detailed qualitative and quantitative analyses of pre-consumer textile waste in Macedonia. These investigations revealed that a significant portion—often exceeding 10% of the total fabric used—was lost during the cutting and sewing stages.

In the study (Jordeva et al., 2015) a characterization of textile waste by type and raw material composition was carried out. The authors found that in the Republic of North Macedonia, cutting waste predominates, consisting mostly of cotton or cotton-blend materials (cotton/polyester). The results of the study were obtained through a questionnaire distributed to top managers of Macedonian textile companies. The main conclusion of this research is that almost all textile waste ends up in landfills, with only about 5% being reused. The main reasons for this situation include the small number of workers available for waste sorting, lack of infrastructure, and limited financial resources. The paper provides a foundation for improving textile waste management and highlights the need for systematic collection and recycling, especially considering that 95% of textile waste can be recycled. Another study, (Jordeva et al., 2018) focuses on accurately assessing the amount of waste generated during garment cutting (pre-consumer waste). The conclusion shows that the average annual amount of cutting waste in the Republic of North Macedonia between 2009 and 2014 was approximately 3,377 tons per year. Even though the quantities remained relatively constant, nearly all this waste ended up in landfills, meaning it was not recycled. One of the more recent studies, (Maksimov et al., 2022) titled develops a new methodology for determining the quantity of cutting waste directly at the point of generation—namely, within garment manufacturing companies. The methodology proposed introduced standardized procedures for measuring the quantity and type of waste produced during the cutting process, enabling better control and monitoring at the industrial level. The research was conducted in three companies, and the results show that the proposed methodology is applicable and can help obtain accurate data on the quantity of cutting waste produced. This systematic approach helped establish a foundation for future waste reduction strategies and sustainable material planning.

### **1.2. Textile waste management practices**

In Europe, textile waste is mainly eliminated through incineration, as landfilling recyclable materials is prohibited ([P6\\_TA-PROV\(2007\)0000](#)). France and Germany have largely closed landfills, while the UK still disposes of about 70% of textile waste this way. Most textile waste in these countries comes from households, with minimal industrial waste, ([Microsoft Word - Report Ouvertes Project June2005.doc](#)). Large-scale apparel production is concentrated in developing countries such as Turkey, Lithuania, and South Africa, selected for comparison with Macedonia due to similar GDP levels ([List of countries by GDP \(PPP\) per capita - Wikipedia](#)). Turkey, one of the top global textile exporters, significantly contributes to global recycling efforts ([World trade report 2011](#)). Its textile industry shows rapid growth, surpassing EU averages in several indicators (Milašius R., et. al., 2014). In 2008, Turkey recycled or sold most of its textile waste, with

only 16% landfilled (Altun S., 2012). Lithuania's waste consists mainly of natural and blended fibers, with about half ending up in landfills (Kazakeviciute G., et al., 2008). In South Africa, most textile waste is landfilled due to limited technology and low disposal costs (Larney M & Aardt AM.) Grasso (1995) highlighted the critical importance of properly sorting and packing apparel waste, noting that it must be clean and free of contaminants to transform it from garbage into a valuable resource. Furthermore, he observed that bailing apparel waste, rather than packing it in boxes or bags, enhances its suitability for sale.

As the understanding of textile waste grew, subsequent research (Maksimov S. et al., 2022; Zhezhova S. et al., 2022) examined the management practices implemented by apparel producers in North Macedonia. These studies evaluated the collection, sorting, storage, and disposal methods used by local factories, revealing substantial gaps in both organizational and legislative frameworks. The results indicated that textile waste management in North Macedonia was largely unregulated, with most waste being disposed of in municipal landfills without proper sorting or reuse. The research also highlighted the lack of awareness among factory managers regarding the economic potential of waste recycling and reuse. These findings underscore the necessity of a structured national strategy for textile waste management, emphasizing collaboration among government, academia, and industry. The papers proposed the establishment of regional waste collection centers, incentives for recycling initiatives, and the integration of waste management education into technical curricula.

### **1.3. Attitudes and awareness toward waste management**

A parallel line of research, represented by Attitudes Towards Managing Post-Industrial Apparel Cuttings Waste (Tomovska E. et al., 2017), explored the behavioral and managerial dimensions of waste handling in the textile industry. Surveys conducted among textile company managers revealed that economic considerations, lack of recycling infrastructure, and limited access to innovation were major obstacles to adopting sustainable practices. These insights highlight the importance of continuous education, capacity-building, and the dissemination of best practices across the textile sector. The authors recommend developing public-private partnerships and implementing pilot recycling projects to demonstrate the feasibility of sustainable textile waste management.

### **1.4. Innovative utilization of textile waste**

The second focus of this research is on papers that propose innovative materials made from textile waste. In this context, the study titled 'Application of Apparel Cutting Waste as Insulation Material' is particularly noteworthy because it "Application of apparel cutting waste as insulation material" (Jordeva S. et al., 2014) is interesting. The research team demonstrated that textile waste could serve as a viable alternative to conventional insulation materials. The study designed new insulation material (for partition walls in buildings) and conducted tests to evaluate its physical properties, thermal conductivity, and potential to replace traditional insulation materials. The thermal conductivity coefficient ( $\lambda$ ) of the new product was compared with standard insulation materials. The results show that the thermal conductivity coefficient  $\lambda = 0.05198\text{--}0.06032$  W/mK. The material demonstrates sufficient mechanical and thermal stability for use as insulation. This indicates a high potential for utilizing a significant portion of textile waste instead of landfilling it. The research paves the way for the practical, value-added use of textile waste and proposes a circular approach: cutting  $\rightarrow$  waste  $\rightarrow$  reuse  $\rightarrow$  insulation. Further studies, (Trajković D. et al., 2017) and (Jordeva S. et al., 2019), confirmed the excellent thermal and acoustic properties of recycled polyester materials. Laboratory tests showed that these insulation panels provided comparable or even superior performance to synthetic insulation products, with added environmental benefits. Moreover, the works presented at international conferences (Jordeva S. et al., 2015; 2016) investigated the fire resistance, sound insulation, and structural characteristics of textile waste composites. The development of eco-friendly insulation materials not only contributes to waste reduction but also opens new markets for sustainable products in the construction sector.

### 1.5. Contribution to sustainable development and circular economy

The evolution of research in this field reflects the broader transition from mere waste disposal to resource valorization, which lies at the heart of the circular economy concept. Over the years, investigations have progressed from identifying and quantifying textile waste to developing sustainable materials and promoting eco-design and waste minimization principles. Recent studies have positioned the Macedonian textile industry within the framework of European sustainability policies, aligning local efforts with global environmental goals including the EU Green Deal and the United Nations Sustainable Development Goals (SDGs). This interdisciplinary research-integrating textile technology, environmental science, and industrial engineering-has established a foundation for incorporating circular economy principles into textile production systems. The findings have contributed to advancing both regional and international understanding of sustainable textile waste management and have inspired new research directions aimed at developing innovative materials, optimizing production processes, and embedding waste reduction within corporate and industrial strategies.

Based on this and other analyzed research, two summary tables were created: one presenting scientific and statistical studies on textile waste in Macedonia, and another comparing regional and European trends. Table 3 presents the main conclusions and trends.

*Table 1: Overview of scientific research and data on textile waste in R. N. Macedonia*

No.	Research / Source	Year	Main Findings	Conclusions
1	Current State of pre-consumer apparel waste management in Macedonia	2015	The research was conducted through a questionnaire in 120 Macedonian apparel manufacturers.	Disposal in landfills is the dominant waste management practice.
2	Qualitative and quantitative analysis of the pre-consumer textile waste in North Macedonia	2022	Investigation of the textile waste quantity and quality as a pre-condition for its further management	Domination of the apparel cutting waste composed of cotton and synthetic fibers, average of 1.42 kg per capita of pure pre-consumer textile waste generated annually.
3	Ministry of Environment and Physical Planning (MoEPP) – Waste Management Report	2023	Macedonia annually generates over 8,000 tons of textile waste.	The recycling system is in its initial phase; 90% ends up in landfills.
4	Circular Economy Project (UNDP – North Macedonia)	2023	Analysis of possibilities for recycling and reuse.	Potential for 20–25% utilization through the introduction of selective collection.

*Table 2: Comparative Data: Textile waste and recycling in the region and the EU*

Country / Region	Year	Generated Quantity (tons)	Recycling / Reuse (%)	Source / Notes
Macedonia	2023	~8,000	< 5%	MoEPP, UNDP (2023)
Bulgaria	2024	> 100,000	2%	novinite.com (2024)
Romania	2024	~160,000	up to 10%	green-forum.eu (2024)
Serbia	2024	~90,000	< 5%	ekapija.com (2024)
Greece	2023	~120,000	5–7%	Hellenic Recycling Org.
EU average (27 countries)	2022	6.94 million	15%	EEA Report (2022)

Table 3. Main conclusions and trends

Category	Macedonia	The Region	The EU
Sorting infrastructure	Insufficient; no separate collection	Similarly low (partially developed in Romania)	Well developed in most countries
Recycling capacities	Minimal, limited to mechanical processing	Limited	Advanced systems (reuse, chemical recycling)
Legal framework (EPR)	In preparation	Early implementation (Romania)	Active in most countries
General trend	Need for systematic waste management	Similar challenges across the Balkans	Moving toward a circular economy

## CONCLUSION

This review demonstrates the growing importance of sustainable textile waste management within North Macedonia and beyond. The analyzed studies in this paper have built a solid scientific foundation for the transition from traditional waste disposal toward a circular economy. The studies have revealed that the majority of textile waste remains unrecycled and underutilized, despite its high potential for reuse in insulation and other eco-material applications. The implementation of standardized waste quantification methodologies and the promotion of awareness across industry stakeholders represent significant steps forward. Future research should focus on scaling up recycling technologies, integrating life-cycle assessment into production planning, and establishing national policies to support sustainable textile practices. This evidence collectively underscores the essential role of innovation, education, and cross-sector collaboration in achieving long-term environmental resilience and industrial sustainability.

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## TRANSFORMATIVE MODULAR DESIGN IN TEXTILE SYSTEMS

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### ABSTRACT

This study presents an interdisciplinary hybrid design approach that explores the intersections between mathematics, art, fashion, and textile design through modular material systems based on geometric forms. The research investigates how modularity can serve as a design strategy for creating adaptable and reconfigurable textile structures that encourage experimentation and user interaction.

The primary aim is to foster active user participation in the design process by enabling interactive, playful, and co-creative experiences. Through modular systems, users are not only consumers but also contributors to the transformation and personalization of textile products. This shift redefines traditional design boundaries and supports a more dynamic relationship between designer, object, and user.

By integrating principles of geometry, system thinking, and material exploration, the study highlights the potential of modular design to generate flexible and multifunctional textile outcomes. It also emphasizes the role of modularity in enhancing engagement, creativity, and customization within fashion and textile applications.

Overall, the research positions modular textile design as a framework that bridges artistic expression, scientific structure, and user-centered innovation, contributing to the development of more interactive and adaptive design systems.

**Key words:** modularity; textile design; co-creation; customization; geometric patterns; symmetry; tessellation; interactive design.

### INTRODUCTION

Modular systems are based on the principle of “minimum inventory and maximum diversity,” a concept widely applied in architecture, engineering, and the natural sciences. These systems consist of standardized units (modules) that can be independently combined into multiple configurations, enabling multifunctionality and the generation of diverse structural outcomes.

Within design discourse, modularity is defined as the extent to which a product’s components can be reconfigured, removed, or added according to a set of rules that either enable or constrain such transformations. In this study, textile systems grounded in modularity integrate the advantages of standardization with flexibility, adaptability, and co-creative potential, thereby enabling a high degree of product personalization.

The design approach is inspired by fundamental geometric structures and natural growth patterns, particularly the principles of symmetry and tessellation, which are explored in the development of modular forms and patterns. Based on these geometric frameworks, a system of interlocking modular elements has been developed for application in textile and fashion design.

These modular components can be freely assembled or disassembled according to user needs, allowing product value to be co-created through the interaction between designer and end-user. This

approach encourages active user participation in the design process and supports flexible transformation and adaptation of textile products throughout their lifecycle.

## **MODULARITY IN DESIGN**

Modularity originated as a system for proportional measurement in classical architectural practice and has since evolved into a fundamental design principle across multiple disciplines. In contemporary design, it refers to the use of standardized units that can be physically and functionally combined into larger, adaptable systems.

Within modern industrial design, fashion, and textile fields, modularity is increasingly applied as a strategy that supports flexibility, efficient assembly and disassembly, customization, and extended product usability. Modular systems enable the development of adaptable configurations, allowing products to transform over time without compromising structural integrity.

A key aspect of modular design is its capacity to support user participation and co-creation. Through interchangeable components, products can be continuously reconfigured, repaired, or adapted, extending their lifecycle and reducing material waste. This adaptability contributes to both functional versatility and increased emotional attachment between users and designed objects.

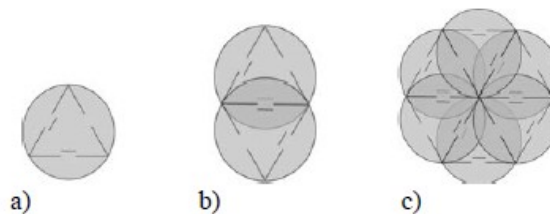
The structural logic of modular systems is strongly rooted in geometric principles such as symmetry, tessellation, and the systematic repetition of basic shapes. Each module functions as a discrete unit within a larger combinatorial system, enabling the formation of complex spatial and material structures through repeated assembly rules.

## **EXPLORING MODULAR SHAPES**

The development of modular textile systems typically begins with the adaptation of simple geometric forms derived from regular tessellations of the plane. Basic polygonal units serve as the foundation for modular construction, where each element is designed to function as both an individual component and part of a larger interconnected system.

Connection mechanisms are integrated directly into the geometry of the module, enabling controlled interlocking between adjacent units. Through repeated assembly, simple geometric forms can generate more complex configurations, such as multi-unit structures with increased spatial depth and surface variation.

The interaction between modules may also produce layered effects and secondary structural patterns, enhancing both the visual and tactile qualities of the textile surface. In this way, modular systems demonstrate how geometric simplicity can be transformed into complex and adaptable material architectures through rule-based assembly and spatial organization.



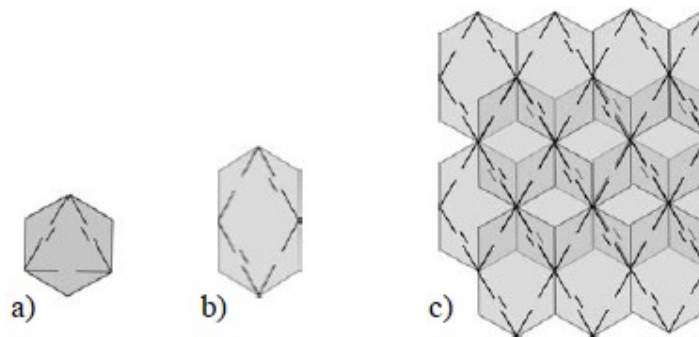
*Figure 1: Modular system based on equilateral triangles illustrating (a) the basic triangular module; (b) the interconnection of two modules forming a rhombic unit; and (c) the assembly of six modules creating a hexagonal configuration*

## TRANSFORMATIVE MODULAR TEXTILES

Additional modular systems were developed by extending the previously defined interlocking framework. One such system is based on an equilateral triangular module inscribed within a hexagonal boundary. In this configuration, the tab elements generated by the hexagonal structure form isosceles triangular extensions, each corresponding to one-third of the area of the primary triangular unit.

Unlike the previously described modular series, the interconnection of modules in this system produces a precisely aligned secondary layer of tessellation. Instead of overlapping material strata, adjacent modules generate a controlled and continuous surface alignment, resulting in a more structured double-layered geometric composition.

The visual and structural clarity of the system is particularly enhanced when modules of different colors are combined, emphasizing the underlying geometric relationships. A rhombic configuration can be obtained through the interconnection of two triangular modules, following the same assembly logic as earlier systems. Furthermore, when multiple modules are combined, the secondary tessellation layer formed by the interlocking tabs produces a linear visual pattern that extends across the rhombic framework, reinforcing the overall modular structure and its spatial continuity.



*Figure 2: Modular system illustrating (a) the initial triangular unit; (b) the derived rhombic configuration; and (c) the tessellated assembly of rhombic modules.*

Further development of the modular system introduced the principle of self-similarity through the integration of elements at different scales. This strategy significantly increased the overall complexity and adaptability of the resulting textile structures.

The system demonstrates how combinations of modules of varying sizes can generate coherent tessellated compositions while maintaining consistent structural logic. Larger and smaller units are designed to remain compatible within a shared connection framework, enabling flexible and scalable assembly.

This approach is further expanded by introducing variable connection interfaces within a single module, allowing interaction between elements of different dimensions. As a result, a multi-scale modular system is achieved, capable of producing self-similar and adaptable patterns through repeated recombination.

Further experimentation explored the integration of modules in different colors, which contributed to enhanced visual and textural variation within the assembled structures. This approach demonstrated how color differentiation can reinforce the perceptual complexity of modular systems. In addition, a range of material options was investigated in relation to their suitability for applications in fashion and

interior design contexts. The selected materials included natural and composite-based textiles as well as wood-based elements, combined with digital fabrication and surface treatment techniques.

Manufacturing approaches such as laser cutting, printing, and surface modification processes were considered to support precise material transformation and enhance the aesthetic and functional qualities of the modules. The results illustrate the potential of modular systems to operate across multiple material and application domains, including both wearable and spatial design outcomes.



*Figure 3: Modularity and Upcycling in Fashion: Temporary Trend or Long-Term Sustainable Approach*

The modular system enables a high degree of user flexibility in arranging and recombining textile units, allowing the overall form to evolve dynamically through interaction. This results in adaptable and structurally varied compositions that can range from simple repetitive arrangements to more complex configurations incorporating modules of different scales and geometries.

Initially developed as a tool to support participatory design methodologies, the system also demonstrates potential for educational applications, particularly in supporting the understanding of geometric relationships, spatial reasoning, and structural composition through hands-on exploration.

### **USER ENGAGEMENT IN TRANSFORMATIVE DESIGN**

User engagement in design is based on the principle that end users can actively contribute to the shaping of products and outcomes. Within this framework, co-design approaches emphasize collaboration between designers and users, promoting inclusive, participatory, and user-centered development processes.

Modular design systems are particularly suitable for such approaches, as they allow for flexible configuration, personalization, and iterative transformation. This increases both functional adaptability and experiential value, potentially extending product lifespan through sustained user interaction.

Experimental participatory sessions have demonstrated how modular toolkits can support collaborative exploration and learning-by-doing processes. In such settings, participants are encouraged to experiment with different configurations and make decisions regarding form, scale, material, and visual characteristics.

Through this process, modular elements become tools for continuous transformation, enabling the creation of hybrid and evolving design outcomes. This approach supports collective creativity and knowledge exchange, positioning design as an open, interactive, and socially embedded practice.

## CONCLUSION

The modular textile system presented in this study is based on fundamental geometric principles, particularly simple polygonal forms and tessellating structures. Through a mathematical design logic, these basic shapes can be translated into complex and adaptable textile configurations suitable for both fashion and interior applications. Unlike conventional textile construction methods, the system does not rely on sewing as a primary assembly technique, as textile formation and structural development occur simultaneously through modular integration. This enables a highly flexible framework that supports a wide range of design variations derived from the same underlying geometric system.

Modular textile systems provide the possibility of extended product lifecycles by enabling continuous transformation and reconfiguration. Individual modules can be rearranged to modify surface patterns, color compositions, or overall structural properties, allowing the same system to generate multiple design outcomes. In addition, modularity supports functional adaptability, including repair, replacement, and modification of localized areas without the need to discard the entire product.

Compared to existing modular design approaches, this system expands the range of possible configurations by incorporating greater variability in scale and structural combination. It also explores a broader spectrum of material applications and highlights the importance of further investigation into material durability and long-term performance. Moreover, the role of user participation emerges as a key aspect of modular design development, emphasizing interaction between designer and end user as an integral part of the design process.

Future developments in this field are likely to involve interdisciplinary collaboration and closer integration between designers, users, and production systems. Such approaches have the potential to reshape conventional design practices by moving beyond static product definitions toward adaptive and user-responsive systems. In addition to established sustainability frameworks, modular and transformative design strategies may contribute to emotionally durable, multifunctional products that support reduced consumption and more responsible material use.

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## **TEXTILE AND GARMENT INDUSTRIES IN ETHIOPIA**

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### **1. INTRODUCTION**

Globally, the textile industry in general, and the clothing industry in particular, has a market that is constantly evolving and looking for new areas of operation. The industry touches the lives of all people in one way or another. Clothing, home textiles, technical textiles, industrial textiles, medical textiles, protective textiles, smart or intelligent textiles, there are variations for all consumers, retailers, manufacturers, technologists, engineers and others.

The textile and clothing industry has come a long way from mere artisanal production to organized industry. Starting with the Industrial Revolution, it has gained supremacy over time. The high production of wool, cotton and silk around the world has given a boost to the industry in recent years. Although the industry originated in Great Britain, the art of textile production migrated to Europe and North America after the mechanization of the textile production process in those areas. Asian countries have also industrialized their economies and taken steps to grow this sector. Japan, India, Hong Kong and China have become leading textile producers due to the availability of cheap labor and raw materials, which are very important factors for this industry.

The textile and clothing industry plays a significant role in the development process of both developed and developing countries. With its intensive use of relatively low-skilled labor, this sector has been important in the process of industrial development, as it provides employment opportunities, creating linkages in the potential use of resources for countries like Ethiopia.

In addition to the opportunities and challenges offered by globalization, recent changes in global trade rules have brought some additional opportunities for developing countries, especially in Africa. One example is the African Growth and Opportunity Act ( AGOA ), which facilitates access to the large US market for a range of goods. Similarly, trade arrangements at the global level (WTO and EU, Everything But Arms, EBA ) and at the regional level ( COMESA ), which also have the potential to promote exports.

Many scholars agree that there is no country that has developed its economy without using the textile and clothing industry as a springboard. Textile industry , especially industry clothes , is hardworking intensive industry and creation possibilities for employment more from either which others industries in the economy .

Clothes is basic human need and one from the first ones production activities established in the process industrialization . Therefore is market clothes always sustainably next to food .

Ethiopia is country big diversity . There is numerous agroecological conditions , from dry lowland ( below 1500 meters) below levels sea ) to too humid plateau ( above 2300 meters) above sea level plateaus ). In the elike variations in temperature and precipitation . With with this agroecological zones , it is assumed everything yes Ethiopia there is huge potential for textile industry , because can yes produce one from the finest raw material in industry , i.e. cotton , as by quality so and so quantity , using yours diverse agroecological zone . However , the previous development is far away lower from estimated potential .

Government Ethiopia is identified this one industry like one from the most important for improvement economic development countries . Ethiopia there is one from the biggest markets working forces in sub-Saharan Africa Africans , and the government is planned yes use these opportunities how would attracted foreign direct investments and incentives textile development industries . As result that , this industry there is big potential for private investments . Therefore is necessary expand and develop products industries , as by quality , as well as quantities , as would you used private investors , especially economy as a whole . Which I can to be factors advantages for investments in the textile and clothing industry in Ethiopia?

**Global population growth.** Along with food and shelter, clothing is a basic human need and one of the most attractive commodities on the international market. Therefore, as the population grows, so does the demand for clothing.

**Economic growth.** The quantity demanded for clothing and apparel increases with income until the income elasticity of demand for the good reaches zero. This shows that there is a direct relationship between economic growth and the demand for clothing.

**Global trade barriers.** Global trade barriers are an important economic variable that affects the sale and purchase of clothing products. Trade barriers between countries seriously affect the cost of imports and increase their prices. As result therefore , the product would became less competitive on market .

In that meaning, clothes and products from developing countries enjoy different possibilities, between others, like what are The Act of Growth and Opportunity Africa (AGOA) government United American The State and the " Everything " Program except "(EBA) European Union. Expects everything yes will these possibilities increase competitiveness clothes and products from at least developed countries , and themselves and increase their demand .

**Sales Price.** Price is another factor that determines the quantity demanded of clothing products. What is price products lower , higher is demand for him and himself team enables to the supplier yes penetrate on market and increase own market share

## **2. TEXTILE AND CLOTHING INDUSTRY IN ETHIOPIA**

With the aim of creating jobs for its growing population and becoming a middle-income country by 2030, the Ethiopian government is in the process of adopting an Industrial Development Policy to transform the currently agriculture-led economy into an industry-based economy. Known by to his/her hardworking intensive industry and low capital needs , sector in easy production is given priority in strategy industrialization of Ethiopia. Government intends yes create 350,000 jobs places , especially for young women , only in textiles and clothing industry . Ethiopian textile and clothing industry should would yes acquire stable stronghold on international market .

Earth is succeeded yes attract foreign investors by creating various incentives like what are tax facilities , state-of-the-art infrastructure , comprehensive services for companies and low prices electric At the same time , the energy sector often characterize uncertain conditions work , low pay and inadequate respect social and environmental standards .

The relatively young Ethiopian textile industry continues to face challenges – maintaining a stable and skilled workforce is one of them. Labor turnover and absenteeism are key characteristics of companies operating in Ethiopia’s industrial parks.

Industrialization – particularly textiles and clothing – is a key factor in the Ethiopian government’s drive for economic growth. It will create several thousand jobs for “low-

skilled” workers and, as a result, reduce poverty. This has proven to be somewhat successful in the Ethiopian context. The Ethiopian economy experienced an average annual GDP growth of 9.8% between 2008/09 and 2018/19, and poverty rates are declining. The government’s Growth and Transformation Plan (GTP) II (2016–2020) was the guiding strategy in working towards structural transformation of the economy and classification as a lower-middle-income country by 2025. The plan aimed to create two million jobs in medium- and large-scale manufacturing enterprises.

As international buyers look to diversify their sourcing markets away from Asia, Africa has gained momentum in attracting new investors for textile and apparel manufacturing. Ethiopia as a manufacturing destination is appealing to investors and manufacturers for several reasons. It offers an abundant workforce with competitive wages, cheap and clean energy, free water, generous tax exemptions of between two and ten years, and low rental costs in industrial parks. In addition, newly designed factory buildings in Ethiopia make it easier to meet international occupational health and safety standards and enable environmentally friendly production. As such, they offer a great opportunity to increase compliance with social and environmental standards compared to Asian manufacturing locations. Another advantage in Ethiopia is the future potential for creating a vertically integrated value chain from cotton to textile production, i.e. the finished garment product.

Ethiopia's export-oriented textile and garment industry is mainly located in the country's relatively new industrial parks. The 13 industrial parks contribute 80 to 90 percent of the country's total textile and garment production. The two largest industrial parks are located in Addis Ababa (Bole Lemi Industrial Park) and Hawasa (Hawasa Industrial Park). While Hawasa Industrial Park houses exclusively textile and garment factories, other parks, such as Bole Lemi Industrial Park, welcome investors from a variety of sectors. The industrial parks are organized in buildings, which are large production halls where the complete cycle of garment production is completed. The fabric used to produce the garments is imported, mainly from Asia. The departments are cutting, sewing (including quality control), finishing, ironing, and packaging. These so-called “low-skilled” jobs provide employment for several thousand Ethiopians, mostly young women from rural areas, with relatively low levels of formal education. Working in an industrial park is often an entry point into industrial work and urban life, with the aim of improving their living conditions. Many international brands such as Decathlon, New Balance and Sheffel are manufactured in Ethiopia. Factories can produce clothing ranging from simple T-shirts, to elegant shirts and blouses, to complex outdoor clothing and biker gear.

### **3. GENERAL CHALLENGES FOR ETHIOPIA'S TEXTILE INDUSTRY**

While Ethiopia’s garment industry has driven economic growth and job creation, curbing urban unemployment rates of over 20% before the pandemic, major challenges continue to hinder the country’s potential to become a new manufacturing hub. With the global slowdown in apparel consumption due to the COVID-19 pandemic and the global recession, as well as internal conflict in Ethiopia, the garment industry was further negatively affected when Ethiopia lost its beneficial trade access to the US market due to the suspension of the African Growth and Opportunity Act (AGOA) effective January 1, 2022. With more than 80 to 90% of Ethiopian garment exports previously going to the US market, the suspension of AGOA has caused a significant drop in orders and therefore exports, a flight of buyers from the country, and mass layoffs of workers in industrial parks. Moreover, the industry is still dependent on imports of raw materials, such as cotton and fabrics, as cotton production in

Ethiopia has not yet reached the demands of international buyers in terms of either quality or quantity.

Given that the sector is still relatively young and the country is heavily dependent on the agricultural sector, the manufacturing industry still struggles to create and maintain a stable workforce. High levels of turnover and absenteeism limit the sector's potential by causing low productivity levels and high costs for regularly hiring new workers. Looking at monthly employee turnover rates, one HR manager reported an average of 6.5% (2-10% minimum and maximum turnover) in his company. Other HR managers reported monthly turnover rates between 3 and 9%, meaning that annual turnover rates can be 50% and higher in textile and clothing companies. Yet the situation is heterogeneous: One HR manager reports an annual turnover rate of 15% for his company and notes that "this is very good because others have around 35% and more than them". Managers plan their operations assuming a daily absenteeism rate of 5%. According to the managers, the reasons for workers' absenteeism and turnover are mainly their "mindset" and lack of experience with formal paid work. Most of the workers come from rural areas, have an agricultural education and have never worked in a factory before.

#### **4. WORKFORCE AND WORKING CONDITIONS**

Most of the lower-level workers employed in garment factories are young women who have migrated from rural areas to urban cities in search of work or because they were directly recruited in their kebeles, or local municipalities.

According to research conducted in the context of the JLU study on labor turnover and absenteeism, most workers are between 20 and 22 years old, and very few are older than 25. Most workers have completed primary school from 10<sup>th</sup> to 12<sup>th</sup> grade or have a diploma. The main motivation for workers to engage in formal work in the textile and garment sector is to gain financial independence from their families, and even to support them. A common saying among operators is "I want to change myself".

Many employees, especially at Hawassa, work in textile factories to finance their studies.

The vast majority of operators work from Monday to Saturday. Standard working hours are 8 hours per day, while overtime can result in up to 10 hours per working day. Ethiopian labor law allows a maximum of 12 hours of overtime per week (including Sunday work). The standard weekly working hours are 48 hours. Companies work in one or two shifts, the latter being more common in the Hawassa Industrial Park. According to employees, the workload is challenging. Two-thirds find their job stressful or very stressful, both in terms of the number of working hours and the daily production targets. Many workers complain about their one-sided working position (mainly sitting). A significant number of respondents complained of kidney problems, which they link causally to the one-sided sitting position.

However, other respondents complained about the one-sided standing position, which workers said could cause problems with their legs and feet. According to GIZ, to reduce the one-sided stress on workers' bodies, factories have begun to introduce higher seats so that workers can change their working position.

The average monthly basic salary was 1,449 birr (excluding incentives and bonuses, and the figures are based on the 2020-2022 survey period), while the lowest-earning respondents received 700 birr as a basic salary. Starting levels of basic salaries are lower than advanced levels. In addition to the basic salary, factories pay incentives, bonuses, and allowances. These include an attendance bonus (200-250 birr) and a productivity bonus (300-500 birr). Workers who come in every working day of the month receive the full attendance bonus.

When workers miss work days, the bonus is either deducted from the first day of absence or is deducted gradually. Productivity bonuses are paid whenever a line or individual worker manages to meet the daily production target.

Finally, factories also provide food and transportation allowances. These are either paid or provided to employees free of charge.

Many factories have cafeterias that serve injera (a local staple made from teff) with various sauces and vegetables. Although this is subjective, more than 70% of respondents rated the quality of the food as poor or very poor.

Many study participants stated that their salary levels do not allow them to financially support their families. Instead, their families support them to maintain their lives in the city and complete their education. The vast majority of respondents would not be able to live on their salary (including incentives such as variable pay). Most workers believe that there is a discrepancy between the volume of work and their salary, which is further exacerbated by high inflation. Many respondents say that they would be satisfied and see their future in the factory if the salary were adequate and the quality of food improved. For all other challenges, solutions could be easily found, according to the workers.

## **5. INDUSTRY POTENTIAL AND PROSPECTS**

Given Ethiopia's large young population of over 30 million citizens aged 15 to 29, coupled with an urban unemployment rate of over 20 percent before the COVID-19 pandemic, private sector development in the country is crucial for job creation, foreign exchange earnings, and export generation. While the manufacturing sector attracted 50 percent of total foreign direct investment in Ethiopia in 2019, investment alone does not guarantee the sustainability of job creation and economic growth. In addition to the country's challenging political context, key factors such as a lack of financing, sector-specific technical skills, and strategic coordination among stakeholders, as well as inadequate compliance standards and industrial labor culture, have hindered Ethiopia's sustainable industrial growth. However, the light manufacturing sector remains important and resilient in the path of economic growth. The textile and clothing sector accounted for more than 36% of manufacturing industry exports (US\$181 million) in 2021/22 and continues to be labor-intensive, employing up to six times more people (the vast majority of whom are women) compared to other manufacturing sectors.

The Ethiopian textile and garment industry and its state-of-the-art industrial parks are unique in sub-Saharan Africa. Central to the success of the light manufacturing sector has been a committed government, systematic financial and technical assistance from development partners and – above all – the high availability of a “low-skilled” workforce. However, given the sector's nascent stage, absenteeism and employee turnover rates are high, especially in the first three months of an operator's employment. Research has shown that higher wages can particularly reduce worker turnover and could further increase productivity.

Ethiopia's textile experiment is at a critical juncture: it is time to strengthen the sector and create an enabling environment to attract more investment and ultimately create decent jobs. This is a challenge for the government, for investors, for the management of industrial parks, for international development cooperation and, ultimately, for the largely female workforce, on whose cooperation and resilience the future prospects of the textile industry as a labor-intensive sector depend.

The next phase will focus on upgrading the Ethiopian textile and clothing sector to meet the demands of international markets in an increasingly competitive market environment. The focus remains on strengthening the economic, social and environmental sustainability of the

industry through activities to promote worker well-being, improve the sustainability of production processes and strengthen the regulatory framework for a just transition of the sector. It will also support private sector and government partners to ensure their readiness for new international supply chain due diligence regulations.

## **6. EFFICIENCY IN FACTORIES**

Factory efficiency can often be slow, affecting production volumes by between 40 and 45 percent. Processes need to be developed and the workforce needs more education. Cycle times can be up to 150 days due to a shortage of raw materials. Only 40 percent of the materials needed are available in Ethiopia, while the remaining 60 percent are imported. Compared to other countries, production and sourcing can take 45 to 60 days longer. Challenges also include limitations in technology, especially in digital transaction processing. At the same time, international buyers have raised social and environmental standards in recent years, driven by increased consumer demand for fairly produced clothing. Growth in the sector and its establishment in Ethiopia must be sustainable, in line with international standards and regulations.

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## KITSCH IN CLOTHING PRACTICE

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### ABSTRACT

The paper examines the emergence of kitsch as a form of artistic practice that pretentiously imitates beauty and emotion, in a way where artistic expression becomes superficial and unoriginal. Without an original and honest foundation, kitsch tries to impose itself as a work of artistic value, evoking emotions in the consumer in a superficial and meager way. Kitsch and fashion share a common goal — both strive for commercial success and often imitate artistic practices that cyclically reappear within the fashion system. Kitsch appears when design in clothing lacks essence and is based solely on external effect or surface expression of ideas. The visual expression of fashion discourse then loses the balance between expressiveness and good taste. When decorative elements are placed before the fundamental concept of a garment, we create space for kitsch to emerge. In contemporary clothing, some designers consciously use kitsch as a starting point, and thus play with the aesthetics and taste of consumers.

**Key words:** kitsch, fashion, subculture

### INTRODUCTION

Fashion has long ceased to be the exclusive domain of the elite or the epicenter of aristocratic society. What once emerged as a phenomenon “from the top down” has transformed into a privilege accessible to a much broader social spectrum. Clothing practices are now directly shaped by *consumer policy*, driven by the growing consumerism of modern life. Through dress, we engage in a form of non-verbal communication with our surroundings — expressing our habits, social belonging, material status, and other elements that define our identity. Advancement on the social ladder inevitably creates the desire for status to be represented through visible symbols.<sup>1</sup> Clothing, as a wrapper of the body, has long ceased to be merely a functional shell. In our language, the term *fashion* most often refers to current trends in dressing, while in reality, fashion represents a much broader discourse. It encompasses contemporary tendencies and trends across various fields of applied and visual arts, architecture, film, literature, and other areas of culture. In the lexicon of foreign words, the term *fashion* (*fr.* mode, *lat.* modus – manner, way) denotes mood, taste, custom, and the style of dress and appearance characteristic of a certain period.<sup>2</sup>

It is precisely *taste*, as an inseparable companion of fashion, that defines the aesthetics of a given era. There is a saying that *taste should not be disputed*, although today there would be much to say on this subject. The idea of the “*best taste*” or a “*recommended functional system*” cannot be objectively confirmed when it comes to fashion.<sup>3</sup>

In his writings, Gillo Dorfles reflects on both the positive and negative aspects of fashion, which are fundamentally rooted in the problem of taste. What we call “*bad taste*” can be categorized as *kitsch* — a phenomenon that promotes false imitation, lack of originality, and a cheap, overly sweet appearance, all in an attempt to appeal to a broader audience.

In a spiritually weakened society with low intellectual capacities, *kitsch* easily finds its foothold and conquers the masses. Moles’ assertion points to the human predisposition toward kitsch — a reaction

to previously formed inclinations that stem from a lack of education rather than from victimhood.<sup>4</sup> As part of the creative industry, clothing practice provides a favorable arena for the production of kitsch. Every day we witness inauthentic and one-dimensional artifacts within this field. The unlimited reproduction of products is one of the defining features of *kitsch*, something we continuously witness in the clothing industry. In their pursuit of sensation, individuals easily slip into a vulgar, imitative, and “cheap” appearance. The accumulation of garments — discussed by Baudrillard in *The Consumer Society* — points to a transformation in the consumer’s relationship with objects, which, as he writes, “no longer refers to a specific object in its individual utility, but to the entire set of objects in their total meaning.”<sup>5</sup>

Here we encounter the phenomenon of collecting and accumulating whole groups of items, organizing them into cohesive ensembles. In clothing practice, this is particularly evident, as we are often conditioned to purchase multiple garments in order to complete a single outfit. In the same work, Baudrillard defines *kitsch* as simulation, copy, imitation, stereotype — a state of scarcity in real meaning and an excess of signs.<sup>6</sup> The fashion industry, through all its mechanisms, strives to stimulate consumption and create in consumers the desire for new products. Production cycles in the clothing sector have shortened from two collections per year to as many as twenty, as seen with “fast fashion” brands such as Zara, H&M, Benetton, and others. This kind of pressure and accelerated production process, affecting both manufacturers and consumers, inevitably undermines the quality of clothing and accessories, leading to accumulation and more frequent purchasing than real necessity dictates.

During holidays such as Women’s Day, Valentine’s Day, and similar occasions, shop windows are flooded with heart-shaped motifs that *sweetly* and sentimentally appeal to emotional buyers. Such products exist in direct reciprocity between low price and low quality. The fashion industry strives, with each new season, to introduce innovations in form, color, material, texture, pattern, and other elements that constitute its structure, in order to continually stimulate the desire for ongoing consumption. Consumer demand is the decisive force in the creation of fashion.<sup>7</sup>

This applies not only to fashion as a cultural phenomenon but also to the aspects of the production chain that employ a large number of workers and encourage technological development within the sector. The abundance of imitative, disposable goods produced at an accelerated pace is inherently unstable — these products remain on store shelves only for a brief time before being replaced by new ones. The historical study of fashion reveals numerous examples of *bad taste*, which become easily recognizable when observed from a temporal distance. We do not need to look far into the past to find such instances — many can be found even in the recent history of fashion. In his book *Fashion – An Iconographic Investigation*, Gillo Dorfles points to high heels and cork-soled shoes as examples that, while appearing highly appealing at a certain moment, soon acquire the label of *bad taste* once the fashion for wearing them fades.<sup>8</sup>

Dresses with excessively wide sleeves, awkward silhouettes, short skirts, lurex trousers, platform shoes, and torn or worn-out suits are just some of the elements often deemed socially unacceptable, as they falsely “correct” the body. Such oversized or minimized garments appear absurd because they disregard bodily proportion—a concept also shaped and codified by contemporary trends. Fashion is often associated with kitsch; it adopts kitsch elements and reinterprets them as modern. We were once unaware of our attraction to current trends, wearing what was fashionable and contemporary, only to later categorize those same choices as kitsch. Were the teased, bleached hairstyles, exaggerated

shoulder pads, and neon colors of the 1980s kitsch? From today’s perspective—yes, although they were not perceived as such at the time. Kitsch is like the “sweet, sticky” cellophane around a candy—it helps us more easily grasp the absurdity of fashion. Fashion is defined by novelty, the fundamental element of its very existence. Being “modern” is synonymous with being “new.” Within the cycles of emerging trends, it is difficult to maintain uniqueness and originality; this very ephemerality allows kitsch to flourish. The excessive need to decorate and embellish garments with superfluous details for the sake of appeal and ornamentation remains a common phenomenon in this field.



Fig. 1 *Western style*



Fig. 2 *Punk fashion*

The subcultures of the twentieth century brought together groups of people who shared the same goals, attitudes, opinions, and needs, shaping them into creative uniforms in contrast to mainstream fashion. The so-called “style supermarket” unified subcultures such as funk, hippie, surfer, teddy boys, western, rock, glam, goth, punk, and others. Their members adopted distinctive dress codes through which they could identify one another and communicate using specific sartorial signs.

Characteristic of the Western style that defined the 1940s in America was a longing for rural life during a time of rapid urbanization and migration to cities. The urban cowboy nostalgically continued to wear

the attire of his homeland plaid shirts, cowboy boots, and hats. Kitsch, as a product of the Industrial Revolution and the processes of urbanization and mass migration, emerged when the new social strata no longer had the time to engage with traditional urban culture. It thus came to define the value and necessity of creating new cultural forms. Their habits and needs gave rise to authentic yet appealing products tailored to consumers of that social level. On the other hand, the punk subculture was ideologically the antithesis of everything natural and inclined toward peace and love. In contrast to the hippie movement whose many followers protested against the senseless suffering caused by the Vietnam War punk embraced aggression, vulgarity, and a sense of hopelessness. Instead of the rustic caftans, braids, and embroidered skirts worn by nature-inspired hippies, punks adopted heavy boots, leather jackets and trousers, ripped T-shirts fastened with safety pins, chains, and metal accessories.

Slogans such as “No Future” and “God Save the Queen” were written across their clothes, linking them to ideas of relativism and the fragility of life. Nihilism, disillusionment, spectacle, and rebellion were among the key concepts through which members of the punk subculture defined their identity. All the elements of identification incorporated into punk fashion ultimately turned the punk into a victim of fashion itself — in contrast to the dominant culture, aestheticized according to the ideals of Western society.



Fig. 3 Backpack with a picture of the Mona Lisa



Fig. 4 Moschino Eyewear campaign 2023.

The acceptance of new values in clothing culture and a particular lifestyle marked a period of social transformation that flirted with various fashion dictates, where imitation and “bad taste” became inevitable. Certain elements can be regarded as kitsch from the moment they emerge such as traditional folk costumes when adopted by the bourgeois class. The youthful energy of subcultures reinterpreted fashion symbols, transforming them into authentically expressive and unconventional forms. Although, from today’s perspective, these styles may appear overly stylized and kitsch, they succeeded in reviving a new understanding of fashion—one that had long been suppressed by the elitist codes of dress. An individual belongs to a particular group because they consume certain goods, and they consume these goods because they belong to that group.

Sociologically, this reflects the relationship between the individual and the group, involving an analogy between idealism, pleasure, and excitement. The acceptance of certain dress codes as a means of belonging to a specific group has led to the “degradation” of fashion manifested through flattery and the investment of effort merely for the sake of survival within such an environment. We are witnessing an explosion of tourist destinations where cultural institutions offer kitsch souvenirs such as the Mona Lisa, Van Gogh’s “Sunflowers,” and other popular artworks to visitors. One would expect that

museums and major galleries, of all places, would be exempt from such decorative trivialities, precisely because of their overtly indulgent character. Printed on bags, T-shirts, caps, and similar items, these motifs become easily available at modest prices, though completely removed from their original context. Among various kitsch objects, the silk scarf printed with a “famous painting” stands out as a luxury souvenir, representatively sold in museum shops at a price that is far from negligible indicating that kitsch products can also reach high financial value. *Kitsch, as a concomitant phenomenon of mass culture in a broader sense, is reflected in the fashion production of clothing designed to be appealing and attention-grabbing. It is important to emphasize that fashion is defined by novelty—the key element of its existence. Being “modern” is synonymous with being “new.” In the cyclical nature of fashion, it is difficult to achieve uniqueness and originality, and its inherent*

*ephemerality creates fertile ground for kitsch to thrive. In the pursuit of sensation and greater visibility of trends, individuals often slip into vulgar, accessible, and cheap appearances.*

*Kitsch would not exist without a market and consumers who adopt it and take pleasure in its playfulness and decorative appeal. This leads to a loss of measure and the accumulation of aesthetically low-value content within the fashion discourse, which continues to expand. Fashion has succumbed to the influence of the masses and the global market, subordinating its primary functional purpose to aesthetic discourse and failing to emancipate the consumer. As a faithful follower of fashion—stealthy, nostalgic, and sugary—kitsch appears without an original idea, yet continues to captivate new audiences.*

## CONCLUSION

Kitsch and fashion are multi-layered companions in the mega productive landscape of contemporary society. Not everything modern is kitsch, yet it is often difficult to draw a clear line separating these two opposites within the vast sea of styles. Each day we witness serial reproductions—copies of originals—that flood the market and gradually strip the original creation of its meaning. Easy accessibility and sensory appeal make kitsch a convenient medium through which fashion artifacts are shaped. As an omnipresent element of mass culture, it is nearly impossible to avoid—it surrounds us everywhere. Superficiality, a low educational threshold, and spiritual emptiness form the ideal stage for the development of kitsch. The fashion industry sublimates various creative factors such as photography, catalogues, and video content, which bombard us daily with the intent to shape and manipulate our taste. Kitsch products aim to offer the modern individual pleasure and satisfaction without demanding much effort or interpretation. These kitsch replicas entertain us, lift our spirits, and provide a fleeting sense of happiness and fulfillment—which, paradoxically, represents the positive side of fashion

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[file:///kic-ratko-bozovic\\_compress.pdf](file:///kic-ratko-bozovic_compress.pdf)

#### **SOURCES:**

Fig. 1 <https://ar.pinterest.com/pin/857724691539469329/>  
Fig. 2 <https://www.pinterest.com/pin/27584616457411679/>  
Fig. 3 <https://lifestyle.bg/art/kich-ili-avangardna-moda.html>  
Fig. 4 <https://www.thelionsmanagement.com/stories/campaigns/270-maria-keidj-moschino-spring-summer-2023-eyewear>

## **MODULAR DESIGN IN CONTEMPORARY FASHION: DEVELOPING STANDARDS FOR SUSTAINABLE DESIGN PRACTICE**

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### **ABSTRACT**

The rapid evolution of the fashion industry, accompanied by accelerated consumption patterns, has created an urgent need to rethink conventional design methodologies in favor of sustainability-oriented solutions. Within this context, modular design emerges as a contemporary concept that enables the transformation and extended use of garments through their structural decomposition into interconnected elements. This approach enhances product adaptability to individual user needs while simultaneously reducing material and energy consumption. The focus of this study is the development of a structured set of standards for the implementation of the modular design approach in fashion. The research is based on the integration of theoretical analysis and empirical investigation, conducted using a descriptive methodology. To ensure the validity of the proposed standards, an expert evaluation was carried out involving specialists in fashion and textile design. The findings reveal a high level of agreement among participants, indicating that the proposed standards are clearly defined and practically applicable. The study contributes to the advancement of methodological approaches in sustainable fashion design and provides practical guidelines for the development of innovative and long-lasting fashion products.

**Key words:** modular fashion, sustainable design, transformable clothing, design standards

### **INTRODUCTION**

Sustainable fashion represents a contemporary approach aimed at balancing the needs of individuals, society, and the environment, with a strong emphasis on product quality and longevity. In this context, the way garments are designed and produced plays a crucial role in extending their lifecycle and reducing environmental impact.

Current production and consumption patterns contribute to unsustainable behavior, while consumers increasingly demand products that combine functionality, aesthetic value, and adaptability to their lifestyles. As a result, designers are encouraged to adopt more innovative and responsible design approaches that incorporate sustainability principles.

One such approach is transformable design, which enables multiple uses of a single garment through structural variation. Within this framework, modular design stands out as a particularly effective strategy, as it involves dividing garments into independent yet compatible components that can be recombined in various ways.

Despite its advantages, the application of modular design in fashion remains insufficiently structured. Therefore, there is a need to establish clear standards that can guide its implementation and improve the overall design process.

### **THEORETICAL FOUNDATIONS OF MODULAR DESIGN IN FASHION**

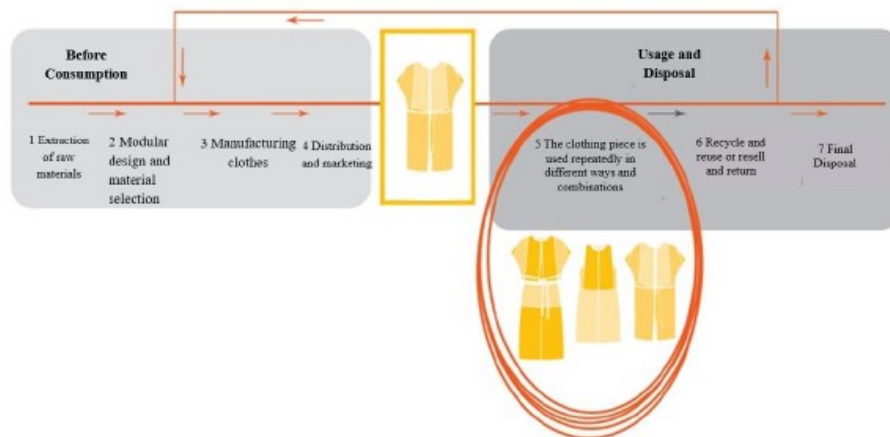
Although early examples of modular fashion were visually striking, they were often perceived as experimental or lacking practical relevance. However, recent developments indicate a renewed

interest in this approach, with increasing emphasis on its functional and sustainable potential rather than purely aesthetic value.

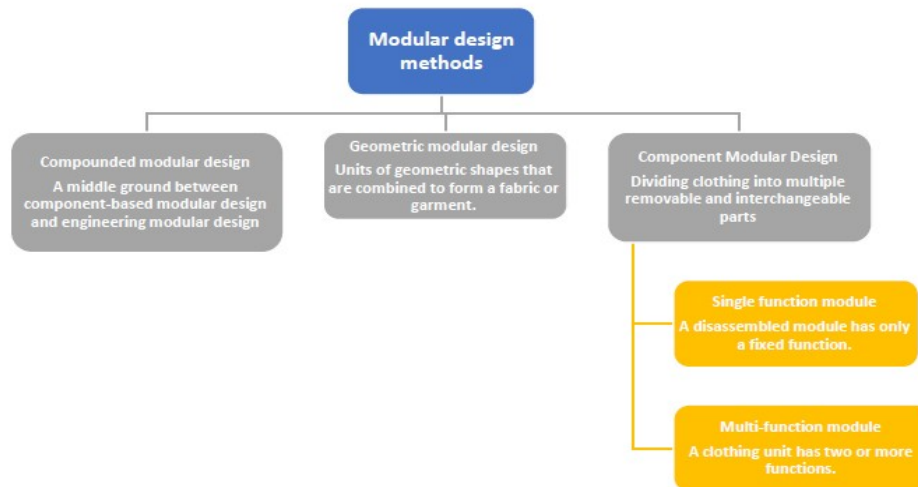
Contemporary designers and brands have begun to adopt modular concepts by creating garments that allow variation and personalization. This enables users to adapt clothing to their needs, reducing the necessity for excessive consumption and promoting more responsible usage patterns.

Within modular fashion design, both aesthetic and functional dimensions are equally significant. Aesthetic quality contributes to emotional attachment and prolonged use, while functionality ensures ease of use, adaptability, and practical performance. Essential functional requirements include module compatibility, ease of assembly and disassembly, and the possibility of repair and maintenance. From an aesthetic perspective, modular garments should maintain visual coherence, balanced proportions, and clarity of form. The application of diverse materials, textures, and decorative techniques enhances their appeal and broad usability.

In terms of sustainability, modular design is characterized by several key features. It enables multiple uses of a single garment through different configurations, supports flexibility across the product lifecycle, and allows continuity by combining elements from different collections. Additionally, it contributes to resource efficiency by enabling selective care and reducing the need for frequent washing, thereby minimizing environmental impact.



*Figure 1: Modular Lifecycle*



*Figure 2: Modular methods*

## DESIGN STANDARDS IN MODULAR FASHION PRACTICE

Design standards represent a set of guiding principles and rules that direct the design and implementation process in order to achieve functional, aesthetic, and practical value. Within this study, which focuses on developing standards for the application of modular design in fashion, a structured methodological framework based on established research procedures was applied.

The aim of developing these standards is to establish a clear and systematic framework that can serve as a practical reference for designers working with modular garments. The resulting standards are organized into three main dimensions: functional, aesthetic, and sustainability aspects. The standards were defined based on a review of relevant literature and applied experimental work, resulting in a total of 20 criteria.

Functional standards relate to the usability and technical feasibility of modular garments. They include design adaptability, an optimal number of modules, precise alignment of structural lines, ease of assembly and disassembly, material quality, freedom of movement, ease of maintenance, and an organized system for storing garment components.

Aesthetic standards focus on visual coherence and product attractiveness. They include design unity, harmony of shapes, lines, and textures, color coordination, balanced decorative elements, innovation in expression, and alignment with contemporary fashion trends while maintaining cultural relevance. Sustainability standards emphasize extending the product lifecycle and reducing environmental impact. They include multifunctionality with a minimal number of components, encouragement of user creativity, reusability and recyclability of modules, and the potential for individual market value of garment elements.

The developed standards were subsequently operationalized into a questionnaire distributed to fashion and textile design experts to evaluate their relevance, clarity, and applicability in practice. Based on the conducted research, it can be concluded that there are no statistically significant differences in experts' opinions regarding the defined standards for applying modular design in fashion practice, which leads to the confirmation of the third hypothesis. This finding indicates a high level of agreement among participants, which may be attributed to the clarity and practical applicability of the developed standards.

The insights obtained from the research suggest that the defined criteria may serve as an important reference framework for modular fashion design. They can support the design process in achieving a balance between creative and functional requirements, thereby improving the overall quality of design solutions.

Although the research demonstrates a strong level of consensus, it should be noted that the importance of specific standards may vary depending on individual design approaches, professional orientation, or aesthetic philosophy. Nevertheless, the absence of statistically significant differences indicates a general agreement among experts regarding the relevance and importance of the proposed criteria.

This research contributes to the development of the theoretical framework of modular fashion design through the establishment of a structured and validated system of standards encompassing functional, aesthetic, and sustainability dimensions. Unlike previous approaches that addressed isolated design elements, this study integrates multiple dimensions into a unified framework.

From a practical perspective, the research helps address the lack of standardized guidelines for implementing modular design in the fashion industry. The validation of the standards through expert evaluation confirms their applicability and relevance in contemporary practice, further strengthening the connection between theoretical models and real-world industry needs.

## CONCLUSION

This study focused on the development and validation of standards for applying the modular design approach in fashion, with the aim of establishing a clear and applicable framework that integrates functional, aesthetic, and sustainability dimensions. The findings indicate that the proposed standards form a coherent and practically applicable system that can contribute to the improvement of design processes within the fashion industry.

Based on the conducted analysis and expert evaluation, a high level of agreement among specialists was confirmed regarding the relevance and applicability of the defined criteria. This suggests that modular design, when supported by well-defined standards, can serve as a sustainable and functionally efficient approach in contemporary fashion design.

The study further highlights the importance of systematizing design principles within modular fashion, particularly in response to increasing demands for sustainability and product flexibility. In this way, the research contributes to bridging theoretical concepts with practical application in design practice.

Despite certain limitations of the study, particularly regarding sample size and the scope of expert evaluation, the findings provide a foundation for future research and further development of standards in the field of modular fashion design.

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## SMART CLOTHING IN HEALTHCARE: REVIEW

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### ABSTRACT

Smart clothes represent important progress in today's healthcare, which provides new opportunities for continual monitoring of health and individual treatment. At the same time, this new technology enables noninvasive measurements of physiological parameters such as body temperature, heartbeat, hydration, and many others by just implementing small sensors in the clothes fabric. All of the collected data offer important insight into a person's health and early diagnosis of possible diseases and/or illnesses. Development of the wearable technologies enables patient monitoring at a distance, more efficient treatment of the chronic diseases, and faster recovery treatment. On the other hand, wide usage of this particular technology opens questions about data reliability and privacy. Also there is the constant problem of maintaining and cleaning the treatment of such exceptional clothes. This paper examines the development of smart clothes and their potential to improve healthcare, especially of the cardio monitoring. The special materials, the technology of the sensors, and the ethical considerations of their usage have been presented. Advantages and disadvantages of their usage in everyday medicine inclusion are considered.

**Key words:** smart clothes, healthcare, textile garments, sensors, cardio monitoring

### INTRUDITION

Nowadays, technical possibilities are growing in a wide range of areas. Therefore, people are getting more sophisticated and start to search for the most convenient and technologically equipped items in daily life. With the development of intelligent technologies in the traditional manufacturing industry, a wave of intelligent clothing is in trend, where electronic parts are incorporated into textiles and clothing to make life easier [1]. Smart e-textiles can sense, react, and interact with a range of ambient stimuli conditions and respond to perform a task in a manual pre-programmed processing manner [2].

Textile technology has also been highly impacted by the development of nanometer-scale systems. In the last two decades, advances in nanotechnology and fabrication methods have had huge impacts and brought about tremendous changes in large-area flexible and stretchable electronics. Nanotechnology has contributed significantly to major advances in smart textiles with the incorporation of additive features to increase their commercial value [3].

The global smart textile market is predicted to grow at a rate of 26.2% from 2020 to 2027 [4]. Smart clothing, a subset of wearable technology, integrates sensors, electronics, and advanced fabrics to provide continuous and unobtrusive monitoring of physiological and environmental parameters [5].

Several key factors drive the increasing interest in smart clothing. First, advancements in textile engineering have enabled the development of conductive and flexible materials that can withstand the rigors of daily use while maintaining the functionality of embedded sensors [6].

Smart clothing integrates textile-based sensors and flexible electronics into garments to enable continuous real-time cardiovascular monitoring in daily life. [7]

## TECHNOLOGIES OF SMART CLOTHING FOR CARDIO MONITORING

Less movement, physical activity and the popularization of unhealthy food in combination with stress and pollution cause more and more cardiovascular diseases, which are the leading cause of death in the world, and account for about a third of all deaths, and among them, the most common are ischemic heart diseases and strokes, caused by the accumulation of fatty deposits in the blood vessels. Close to 85% of these deaths are the result of heart attacks and strokes, and more than three-quarters occur in low- or medium-developed countries. It can be considered a major indicator of a global problem that is increasing due to risk factors such as diabetes, obesity, hypertension and unhealthy habits.

Innovations in the textile industry in the smart clothing can significantly reduce the number of deaths in several ways. One way is to use sensors in the wardrobe we use every day to monitor all the important parameters that are key to the early detection of diseases that are the so-called killers and which have major consequences if the patient survives. And surviving patients often have to wait for long and expensive recoveries when it comes to strokes.

Another benefit of smart clothing is that it can monitor parameters during the postoperative course of home treatment for patients who have already had heart surgery and, in the event of an emergency, immediately alert doctors or caregivers.

Textile-based ECG sensors: fabric electrodes and dry-electrode configurations enabling heart electrical activity capture without gels [8].

Conductive threads and e-textiles: interconnects and sensors integrated into fabrics for washability and durability [9]. Biophysical sensors complementary to ECG: textile GSR proxies, skin temperature sensors, and respiratory cues for contextual cardiovascular assessment [10]. Materials and fabrication: nanomaterial-enhanced fibers, hypoallergenic substrates, and stretchable interconnects to maintain skin contact during movement [11]. Signal conditioning and on-textile electronics: flexible analog front-ends, impedance matching, and low-power digitization embedded in garments [12]. Data processing paradigms: edge computing on wearables for real-time feature extraction versus cloud-based analytics for deeper modeling [13]. Interoperability and standards: consideration of common electrical interfaces, calibration protocols, and cross-device compatibility [14].

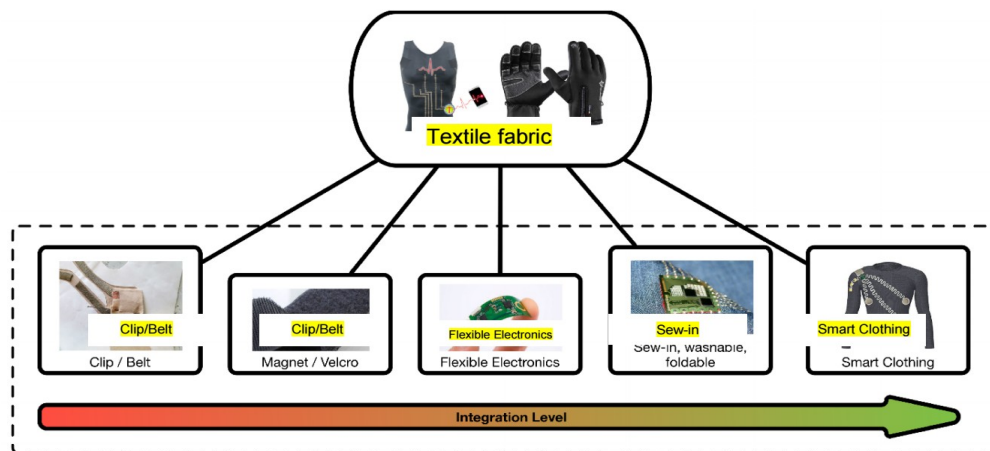
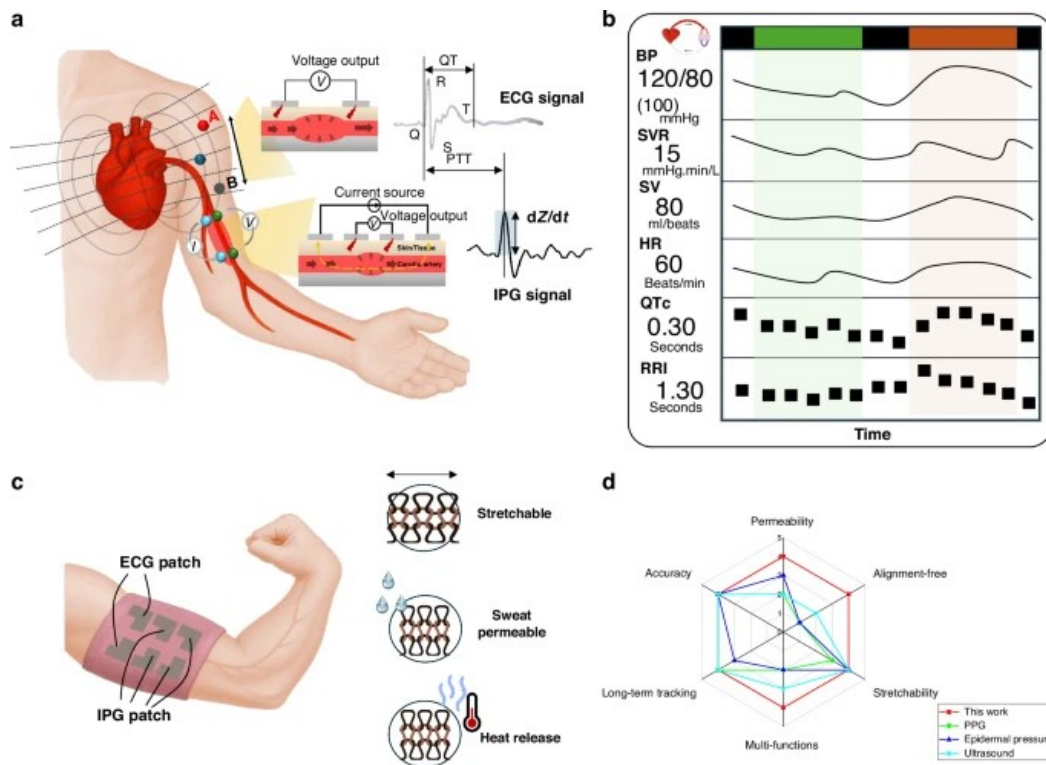


Fig. 1 Integration levels of smart clothing. Adapted from reference [15], originally published under a CC-BY 4.0 licence.



**a** Schematic illustration of ECG and IPG signal generation in the arm and simplified signal model for cardiovascular metrics measurement. **b** Typical cardiovascular metrics measured by the TAESS system. **c** Process and layout of TAESS system. **d** Technical comparison between our system and published works utilizing photoplethysmography (PPG), ultrasound wall tracking and epidermal pressure sensor for continuous cardiovascular metrics (e.g., BP monitoring) in terms of multi-functions, accuracy, long-term track, alignment-free, permeability and stretchability

Fig. 2: Working principle of textile-based cardiovascular hemodynamic measurement [16]

Resistive textile sensors have also been created using conductive fabrics. For instance, the conductive fabrics were employed in the development of textile sensors for detecting strain, moisture, and biopotential, depending on their surface resistance [17]. Keum et al. [18] reported a textile-based strain sensor that employs AgNW/poly(3,4-ethylenedioxythiophene) (PEDOT) conducting fibers, showcasing the feasibility of robust, flexible, and highly conductive fibers for wearable sensing applications. The AgNW/PEDOT conducting fibers leverage both the metal nanowires' high conductivity and the PEDOT matrix's mechanical resilience. This combination enables the sensor to maintain stable electrical paths under repeated deformation, ensuring reliable strain and pressure monitoring over extended use.

The latest developments in the field of smart textiles also enable long-term cardiovascular monitoring as well as continuous monitoring of heart rate (HRV), HRV and rhythm in order to detect deviations at an early stage. By detecting arrhythmia, textile ECG recordings enable discreet screening in everyday life during usual activities.

Also, during the postoperative process, it enables monitoring of parameters and provides insight into the postoperative course.

## CONCLUSION

The adaptive resistant sensors that are part of smart clothing represent a field of research that is expanding and that could directly prevent hundreds of thousands of deaths or long and expensive recoveries caused by heart attacks or heart disease and strokes. Also, during monitoring, ensuring the comfort while wearing and allowing to the users to perform daily tasks, while smart clothing monitors all vital parameters and monitor any deviations that should worry the user.

In most countries, diagnostics and access to doctors are not always available to patients and short-term tests do not always provide a good insight into the cardiovascular health of patients, nor do they always have a good view of the heart's work and the rise in blood pressure during the patient's activity. Smart clothing allows parameters to be monitored almost 24 hours a day and to notify doctors and caregivers in emergency cases. Further development of this type of technology could go in the direction of even more resistant sensors and electronic devices with even smaller boards and sensors that will be even more resistant to maintenance. Also, further research should go in the direction of these devices being powered by body temperature and having the ability to regenerate themselves in the event of damage.

Certainly, further development of this type of technology provides hope that many lives will be saved, but we should not exclude the need for early education of the population in order to prevent cardiovascular diseases and that there is no alternative to a healthy lifestyle, as well as that it has always been cheaper and smarter to prevent than to treat.

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## DESIGN AND CALCULATION OF THE TRANSMISSION SYSTEM IN A MODERN SPINNING MACHINE

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### ABSTRACT:

*In the modern textile industry, spinning machines represent a key part of the production process, with the transmission system playing a decisive role in ensuring stable and synchronized operation of all working elements. This paper presents the design and calculation of the transmission system of a modern spinning machine, with special emphasis on the relationship between drafting roller speed and spindle rotational speed, electric motor selection, and the influence of the transmission system on yarn quality. The main elements of the transmission system, such as the electric motor, gear and belt drives, shafts, bearings, and couplings, are analyzed with consideration of technological and structural requirements characteristic of the spinning process. A practical calculation of the required electric motor power is performed based on realistic industrial parameters, including yarn tensile force, roller peripheral speed, and transmission efficiency. In addition, modern speed control solutions using variable frequency drives (vfds) are considered, enabling soft start, reduction of mechanical loads, and improvement of yarn quality. The obtained results confirm that a properly designed transmission system directly affects machine reliability, energy efficiency, and the achievement of uniform yarn quality.*

**Key words:** spinning machine, drafting roller, spindle, rotational speed, yarn tension, power

### INTRODUCTION

Mechanical engineering in the textile industry is a broad and interdisciplinary field that connects mechanical engineering with textile technology. It includes the design, manufacture, maintenance, and optimization of machines and equipment used in all stages of textile production, from raw material preparation to the final product (yarns, fabrics, knitted structures, etc.).

The transmission system must ensure [Gries T. et al., 2014]:

- accurate speed ratios between individual rollers and spindles,
- stable torque transmission,
- quiet and reliable operation without vibrations,
- the possibility of speed regulation depending on fiber type and required yarn twist.

In the yarn production process, the spinning frame occupies one of the most important positions in the textile industry. Its basic function is the transformation of a fiber strand into yarn through three fundamental stages: drafting, twisting, and winding. In order for these processes to be precise and stable, all rotating machine elements (drafting rollers, spindles, bobbins) must operate in complete synchronization. This synchronization is provided by the transmission system, which transfers mechanical energy from the main drive (electric motor) to the working elements of the machine [Skundric M. et al., 2008].

The transmission system of a spinning frame consists of a series of mechanical components—gears, belts, shafts, couplings, and bearings—that together form a functional unit. Its task is not only to

transmit power, but also to enable precise control of speeds and appropriate transmission ratios between drafting rollers and spindles. In addition, the transmission system must be designed to be reliable, durable, and energy efficient, with minimal maintenance requirements [Ognjanovic M. et al., 2007].

Modern spinning frames are often equipped with speed regulators and variable frequency drives, which allow automatic control of rotational speed depending on fiber type, yarn length, and fineness. Therefore, transmission system design requires knowledge of both mechanical calculations and technological characteristics of the spinning process.

The aim of this paper is to analyze and calculate the basic elements of the transmission system of a spinning frame in order to ensure optimal power transmission and synchronized operation of drafting rollers and spindles, while achieving high yarn quality.

### TRANSMISSION SYSTEM IN A SPINNING FRAME

The transmission system is a mechanical assembly that transmits torque and energy from the motor to the working elements of the machine. In a spinning frame, the main objective of the transmission system is to ensure a precise speed ratio between:

- drafting rollers,
- spindles responsible for yarn twisting,
- winding system (bobbins).

In this way, proper fiber drafting and the required number of twists per unit length of yarn are achieved, directly influencing yarn strength and fineness [Lewis E. et al., 2017].

#### Main elements of the transmission system in a spinning frame

The transmission system typically consists of the components listed in Table 1.

*Table 1. Main elements of the transmission system in a spinning frame [Ognjanović M. et al., 2007]*

ELEMENT	FUNCTION
Electric motor	Source of mechanical energy, usually an asynchronous motor with variable speed.
Gear, belt, or chain drive	Transmits torque from the motor to the main shafts.
Shafts and bearings	Transmit torque to rotating elements while minimizing friction.
Gears	Precisely define speed ratios between individual parts (drafting, twisting, and winding systems).
Couplings	Connect shafts and amortization vibrations
Speed regulator (gearbox, variable frequency drive)	Enables speed adjustment according to yarn type.

#### Transmission system design

In a typical spinning frame, the transmission system consists of an **electric motor** (drive source, usually an asynchronous motor with speed control); **belt and gear drives** (for torque transmission between shafts); **shafts and bearings** (that transmit torque and ensure rotation of working elements); **couplings** (that connect shafts and reduce vibrations); and **gears** (that define exact transmission ratios between individual systems). The type of transmission (belt, chain, or gear) is selected depending on

motor power, rotational speed, and required accuracy. In textile machines, gear transmissions are most commonly used due to their reliability, precision, and reduced slip compared to belt systems [Budynas J. et al., 2011].

### Technological aspect

The transmission system must be designed to enable uniform fiber drafting, ensure synchronization of spindles and rollers, reduce vibration and noise, and allow easy maintenance and long service life [Stepanovic J. et al., 2015].

### Design requirements

The transmission system of a spinning frame must meet the following requirements: high accuracy of speed ratios to ensure stable drafting and twisting, minimal vibration and noise during operation, simple maintenance and lubrication, long service life of elements (gears, bearings, shafts), and the possibility of speed regulation for different fiber types (cotton, polyester, viscose, etc.) [Stepanovic J. et al., 2015].

### Influence of the transmission system on yarn quality

An improperly designed transmission system can cause uneven fiber drafting, yarn breakage, spindle vibration, increased energy consumption, and accelerated machine wear. Therefore, special attention is given to matching drafting roller speed and spindle rotational speed, ensuring a constant twist level and uniform yarn quality [Mihajlovic N., 1985].

## PRACTICAL CALCULATION OF THE TRANSMISSION SYSTEM IN A SPINNING FRAME

### Required electric motor power for driving a spinning machine

The following realistic industrial values are assumed:

- Yarn tensile force:  $F = 20 - 30$  N
- Drafting roller diameter:  $D_r = 0,1$  m
- Transmission efficiency:  $\eta = 0,7$
- Electric motor speed:  $n_m = 1500$  min<sup>-1</sup>
- Drafting roller speed:  $n_r = 1000$  min<sup>-1</sup>

There is no direct connection between the drafting roller and the spindle; rotational speed is transmitted through a gear system.

Typical spindle–roller transmission ratios for cotton and similar fine yarns:

$$i_{sr} = \frac{n_s}{n_r} \approx 5 - 6$$

For a drafting roller speed  $n_r = 1000$  min<sup>-1</sup>, the spindle speed is  $n_s = 5000 - 6000$  min<sup>-1</sup>.

The drafting roller slowly draws and meters fibers, while the spindle must rotate significantly faster to generate sufficient yarn twist, ensure yarn strength, and enable proper winding. Excessive ratios may cause yarn breakage, while insufficient ratios result in poorly twisted yarn [Nikolic G., 2000].

The spindle-to-roller speed ratio is determined by the mechanical transmission system and in this case equals 6, which represents a realistic industrial value. This means that the spindle rotates six times faster than the roller in order to provide the required yarn twist.

The spinning frame drive is realized via an electric motor and main transmission, after which power is supplied to the main machine shaft. From the main shaft, power is divided into two branches: one for the drafting roller drive, where speed is reduced, and one for the spindle drive, where speed is increased. This ensures different operating regimes required for yarn drafting and twisting [Kurban M. et al., 2017].

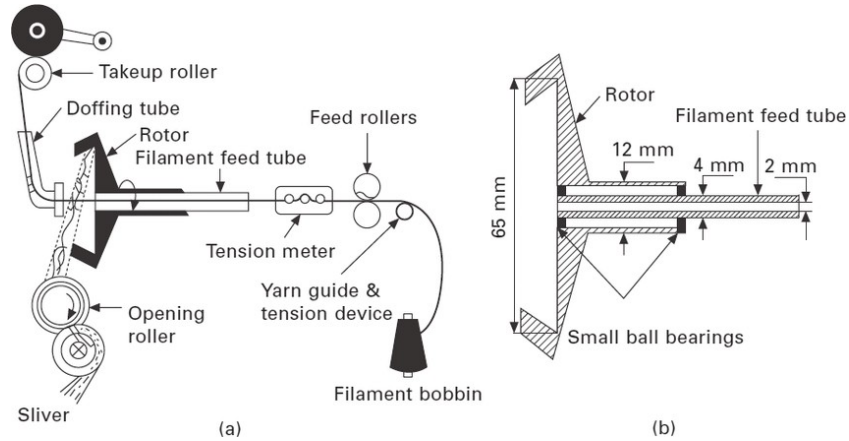


Figure 1: Scheme of the modern spinning process [Kurban M. et al., 2017]

**1) Roller peripheral speed**

Roller peripheral speed is calculated from drafting roller speed and the diameter of the roller:

$$V = \frac{\pi D_r n_r}{60} = \frac{3,14 \cdot 0,1 \cdot 1000}{60} = 5,24 \frac{\text{m}}{\text{s}}$$

**2) Power required for yarn tensioning**

$$P_{\text{korisna}} = F \cdot V = 30 \cdot 5,24 = 157 \text{ W}$$

This is the net useful power acting on the yarn.

**3) Electric motor power**

$$P_m = \frac{P_{\text{korisna}}}{\eta} = \frac{157}{0,7} = 224 \text{ W}$$

**4) Starting reserve**

In practice, a safety factor is taken:  $k = 2,5 - 3$

$$P_m = 3 \cdot 224 = 670 \text{ W}$$

During machine start-up, a higher torque is required to overcome the mass and moment of inertia of the rotating components (drafting rollers, spindles, shafts, pulleys). The electric motor must provide a

sufficient torque reserve to overcome the inertia of the rotating masses and the increased friction occurring during the start-up of the spinning frame.

### **5) Electric motor selection (industry standard)**

Based on the performed calculations, the standard rated power of the electric motor is selected as:  $P_m = 750 \text{ W} = 0,75 \text{ kW}$ .

For a single industrial spinning frame with a drafting roller speed  $n_r = 1000 \text{ min}^{-1}$ , a spindle speed  $n_s = 6000 \text{ min}^{-1}$ , and a realistic yarn tensile force  $F = 30 \text{ N}$ , an electric motor with a rated power of  $P_m = 0,75 \text{ kW}$  is required. This is the reason why, in practical applications, motors with rated powers of 0,75 kW or 1,1 kW are most commonly used.

In modern industrial spinning frames and similar machines, the rotational speed of the electric motor depends on the motor type, the machine application, and the transmission system.

In practice, the following typical motor rotational speeds are used [Hughes A. et al., 2019]:

1. Standard asynchronous motors supplied from the mains (50 Hz):
  - $1500 \text{ min}^{-1}$  (4-pole motor),
  - $3000 \text{ min}^{-1}$  (2-pole motor, higher speed, lower torque).
2. Modern variable frequency drive (VFD) – controlled motors (inverter-driven motors)
  - $300\text{--}3000 \text{ min}^{-1}$ , as required, since speed is electronically controlled,
  - enable increase or decrease of rotational speed, torque control, and soft start and stop,
  - allow precise control of yarn tension and twist level.
3. Servo motors in modern spinning frames:
  - can operate at speeds up to  $5000\text{--}6000 \text{ min}^{-1}$  for very fine or high-speed yarns,
  - the main advantage is direct control of drafting roller and spindle speeds without extensive mechanical transmission systems.

Electric motors with  $1500 \text{ min}^{-1}$  (4-pole) are used in modern industrial spinning machines, but mainly in combination with a variable frequency drive (VFD).

Today, the most common combination in modern industry is an asynchronous motor paired with a variable frequency drive (VFD). The nominal motor speed is  $1500 \text{ min}^{-1}$ , while the actual operating range is  $300\text{--}2000 \text{ min}^{-1}$ . Advantages include soft start (without kicks), control of yarn tension, reduced yarn breakage, and lower mechanical stresses. This setup is now the industrial standard in most textile drives.

In modern spinning machine, rollers and spindles often have dedicated electric motors, with speeds electronically controlled (VFD, servo motors), but the basic assembly principle remains the same.

Table 2 shows the most commonly used combinations in actual industrial plants, where the asynchronous motor is used exclusively with a variable frequency drive (VFD) for tension control and soft start.

*Table 2: Standard motor powers with a variable frequency drive (VFD) in modern spinning machines*  
[Author's elaboration based on: Hughes A. et al., 2019, Boldea I. et al., 2016, ABB Drives – TGB, 2011, El Mogahzy Y.E., 2009, Zatvoreni Trofazni Asinhroni Kavezni Motori, 1973]

Electric motor power (kW)	Nominal motor speed (min <sup>-1</sup> )	Motor operating range (VFD) (min <sup>-1</sup> )	Drafting roller diameter (m)	Drafting roller speed (min <sup>-1</sup> )	Spindle speed (min <sup>-1</sup> )	Yarn tension (N)	Roller peripheral speed (m/s)	Typical application
0,37	1500	300–1200	0,08	600–800	2500–3000	10–18	2,51–3,35	fine yarn, laboratories
0,55	1500	400–1400	0,09	700–900	3500–4000	15–25	3,30–4,24	wool, medium
0,75	1500	500–1600	0,10	800–1000	5000–6000	20–30	4,19–5,24	cotton (standard)
1,10	1500	500–1800	0,10	900–1100	6000–6500	25–35	4,71–5,76	synthetics
1,50	1500	600–2000	0,12	1000–1200	7000–8000	30–40	6,28–7,54	fine / fast yarn
2,20	1500	700–2200	0,12	1200–1400	9000–10000	35–50	7,54–8,80	high-production spinning machine

The motor never operates continuously at maximum power – the VFD adjusts the speed and torque. In practice, yarn tension is controlled by changing the frequency, by PID (proportional integral derivative) torque control, or indirectly via roller speed. The spindle-to-roller transmission ratio averages around  $i_{sr} = 5-7$ . Motor power selection takes into account the starting torque, system inertia, and a reserve for stable operation.

## CONCLUSION

The design of the transmission system in a modern spinning machine represents a complex engineering task that requires simultaneous consideration of mechanical calculations and technological requirements of the spinning process. The presented analysis confirms that properly matched transmission ratios between drafting rollers and spindles enable stable fiber drafting, adequate twist levels, and high yarn quality. The performed calculations indicate that electric motor power selection must be based on realistic operating conditions, including a mandatory power reserve to overcome starting loads and system inertia. The application of variable frequency drives is of particular importance, as they enable flexible speed control, soft start, and reduction of mechanical and dynamic loads on transmission elements. Based on the analyzed examples and industrial data, it can be concluded that the combination of an asynchronous electric motor and a variable frequency drive represents the most common and reliable solution in modern spinning machines. A properly designed transmission system contributes to increased energy efficiency, extended machine service life, and consistent yarn quality, making it one of the key factors for successful operation of textile plants.

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## SMART LOGISTICS PRACTICES SUPPORTING INDUSTRY 4.0 CAPABILITIES IN THE TEXTILE

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### ABSTRACT

*This paper explores the role of smart logistics practices in supporting Industry 4.0 capabilities within the textile industry. The study identifies key technological enablers such as IoT, RFID, cloud-based logistics platforms, predictive analytics, and digital twin systems, which collectively modernize logistics operations and enhance supply chain visibility, automation, and responsiveness. In parallel, organizational readiness factors—including digital literacy, legacy system adaptability, leadership commitment, and change management—are examined as critical conditions for successful adoption and integration of smart logistics tools. The proposed theoretical model highlights the interaction between these technological and organizational dimensions, illustrating how their alignment contributes to digital competitiveness and sustainable advantage in textile firms. The analysis emphasizes that the transformation process is not solely technology-driven but requires a strategic, cross-functional approach that connects logistics innovations with broader organizational goals. This research contributes to the ongoing discourse on digital transformation in manufacturing by positioning smart logistics as a foundational element in building Industry 4.0 readiness in the textile sector.*

**Key words:** smart logistics, Industry 4.0, textile industry, digital transformation, supply chain innovation

### INTRODUCTOIN

The global textile industry is undergoing a period of significant transformation driven by digitalization, rising consumer expectations, and increasing sustainability demands. These pressures are compelling firms to reevaluate the efficiency, transparency, and responsiveness of their supply chains. In this context, smart logistics practices have emerged as a critical enabler of digital transformation, particularly as industries seek to align with the principles and technologies associated with Industry 4.0. The integration of digital logistics tools into the textile supply chain is not only reshaping operational processes but also supporting long-term strategic goals such as agility, traceability, and cost efficiency (Negrete and López 2020).

Within the textile industry, these technologies are particularly impactful across areas such as warehousing, inventory management, transportation, and last-mile delivery. The adoption of Internet of Things (IoT) sensors enables real-time tracking of textile materials and finished goods, reducing uncertainty and enabling responsive decision-making. Radio Frequency Identification (RFID) technologies improve inventory accuracy and speed up the flow of goods across the supply chain. In larger distribution centers, the deployment of autonomous mobile robots and smart conveyor systems reduces manual labor dependency and enhances efficiency (Tiwong et al. 2024). These tools not only improve operational effectiveness but also generate real-time data that can be leveraged for advanced analytics and continuous process improvement. In an industry known for frequent changes in fashion cycles and order variability, such systems allow for dynamic adjustments and quick responsiveness.

Assessing the readiness of textile supply chains to fully embrace Industry 4.0 requires consideration of both technological and organizational dimensions. Although many textile companies, particularly in developed economies, have begun experimenting with digital tools, overall maturity levels remain

uneven. In several cases, automation is limited to isolated applications, such as digital sewing machines or barcode scanners, rather than being part of a fully integrated cyber-physical system. A critical component of readiness involves having a clear digital vision, supported by investment in IT infrastructure, training, and cross-functional coordination. The ability to collect, interpret, and act on data from logistics processes becomes a key indicator of Industry 4.0 capability (Mian et al. 2020). Organizations with legacy systems, fragmented supply chain partners, or limited access to skilled human resources often face setbacks in scaling their digital initiatives. Conversely, companies that view logistics not as a support function but as a strategic asset are more likely to invest in end-to-end digital transformation.

For smart logistics to truly support Industry 4.0 capabilities, it must be strategically aligned with the firm's broader digital objectives. This requires the integration of logistics systems with manufacturing operations, enterprise resource planning (ERP), and customer relationship management (CRM) platforms. Such integration facilitates synchronized planning, reduced lead times, and greater customization of textile products, all of which are central to Industry 4.0's promise. Instead of treating logistics as a cost center, progressive textile firms are beginning to see it as a value driver, capable of enhancing customer satisfaction and market responsiveness. In particular, logistics systems that support mass customization, flexible order fulfillment, and real-time communication with stakeholders offer competitive advantages in an industry characterized by short product lifecycles and volatile demand (Hsu et al. 2024).

Despite its potential, the adoption of smart logistics in the textile industry faces several practical challenges. High upfront costs associated with digital technologies, particularly for small and medium-sized enterprises (SMEs), can limit investment capacity. Resistance to change, often due to fear of job loss or unfamiliarity with digital tools, can also slow implementation efforts. Moreover, integration difficulties between new technologies and existing legacy systems can create bottlenecks and lead to data fragmentation (Gupta, Kusi-Sarpong, and Rezaei 2020). However, there are also clear enablers that support successful adoption. These include supportive public policies promoting digitalization, access to training programs, collaboration with logistics technology providers, and participation in innovation clusters or digital supply chain networks. Firms that recognize these enablers and proactively address the barriers are more likely to navigate the transition successfully and position themselves competitively within the digital economy.

## **TECHNOLOGICAL FOUNDATIONS AND DIGITAL READINESS FOR INDUSTRY 4.0 IN TEXTILE LOGISTICS**

Smart logistics technologies are increasingly becoming a vital component of operational innovation in the textile industry. As this sector evolves under pressure from globalized demand, shorter product life cycles, and rising consumer expectations for both speed and sustainability, logistics functions must undergo a fundamental shift from manual and reactive to intelligent and data-driven. Technologies such as Radio Frequency Identification (RFID), the Internet of Things (IoT), autonomous mobile robots, and advanced warehouse management systems (WMS) are enabling textile companies to monitor, manage, and optimize their logistics networks with unprecedented accuracy and efficiency (Rejeb, Keogh, and Treiblmaier 2019). The integration of these tools allows real-time visibility across the supply chain, enhancing control over raw material inflow, production lead times, warehouse inventories, and last-mile delivery routes.

IoT applications, in particular, offer the textile industry a new level of connectivity. Smart sensors placed throughout warehouses and transportation fleets can monitor conditions such as temperature, humidity, and location, which is particularly useful when handling sensitive or high-value textile goods. This level of monitoring is critical for maintaining material quality throughout the logistics process. RFID tagging is another transformative tool, enabling accurate tracking of goods from

suppliers to production lines and onward to distributors and retailers. In contrast to manual barcode scanning, RFID operates without line-of-sight and can scan multiple items simultaneously, reducing labor time while improving data accuracy (Aithal et al. 2021). Textile companies that rely on just-in-time or made-to-order models especially benefit from RFID's ability to synchronize inbound material flows with production schedules, thereby minimizing waste and overstocking.

Smart warehousing is a central area where logistics technology is reshaping textile operations. Automated guided vehicles (AGVs), collaborative robots (cobots), and conveyor systems are being deployed to streamline the picking, packing, and sorting of textile goods. These innovations not only improve efficiency but also address labor shortages and reduce the risk of human error. Cloud-based warehouse management systems equipped with AI and machine learning algorithms help predict inventory requirements based on sales trends, seasonal fluctuations, and regional demand differences (Rodchenko and Prus 2023). The adoption of such systems enables companies to automate replenishment, dynamically allocate storage space, and reduce lead times. These benefits are particularly valuable in fast fashion and technical textiles, where product diversity and demand variability require rapid and precise fulfillment capabilities.

The readiness of textile supply chains to adopt and benefit from Industry 4.0 technologies is influenced by several interrelated factors. On a technological level, the availability of digital infrastructure—such as cloud computing, secure data storage, and high-speed internet—is a prerequisite for implementing smart logistics systems. However, the presence of technology alone is insufficient without organizational willingness and strategic commitment (Ugrinov et al. 2024). Many firms operate with legacy systems that lack interoperability with modern logistics solutions, making digital transformation fragmented and slow. Additionally, companies must develop internal capabilities through training and recruitment to manage, interpret, and act upon data generated by smart logistics systems (Đorđević et al. 2011).

Cultural readiness is another important dimension. Organizational cultures that support innovation, cross-functional collaboration, and continuous improvement are more likely to succeed in adopting Industry 4.0 practices. Resistance to change, fear of job displacement, and lack of trust in digital tools can create internal barriers that undermine technological investments. Successful implementation therefore depends not only on capital investment but also on leadership commitment to digital transformation and the cultivation of a workforce capable of adapting to new technological environments (Koszewska 2018).

## **STRATEGIC ALIGNMENT AND KEY DRIVERS FOR SMART LOGISTICS TRANSFORMATION IN THE TEXTILE INDUSTRY**

The alignment between logistics functions and broader digital transformation strategies is increasingly recognized as a prerequisite for successful adoption of Industry 4.0 principles in the textile industry. Rather than treating logistics as a downstream operational activity, forward-looking textile firms are embedding logistics into the core of their digital roadmaps. This strategic shift allows logistics to contribute more directly to organizational goals such as customer responsiveness, cost reduction, sustainability, and innovation. The emergence of Industry 4.0 has reinforced the need for seamless integration across all nodes of the supply chain, from sourcing and production to distribution and after-sales service (Farajpour et al. 2022). Logistics sits at the intersection of these activities, making it a critical enabler of digital transformation. The synchronization of logistics data with production planning systems, sales forecasts, and supplier networks supports real-time decision-making and shortens reaction times to market signals.

In the textile industry, where products are often subject to rapid design changes, color variations, and seasonal preferences, logistics alignment with digital strategy enables faster time-to-market. Fashion

retailers increasingly rely on logistics capabilities to support short lead times, agile restocking, and flexible order fulfillment. This level of responsiveness is only possible when logistics systems are designed to communicate continuously with sales channels and production units (Kokeza and Josipović 2023). Furthermore, the integration of logistics with data analytics platforms allows textile firms to monitor key performance indicators such as delivery accuracy, return rates, and customer satisfaction in near real-time. These insights can then inform strategic decisions about product lines, regional distribution centers, or third-party logistics partnerships.

Despite the strategic importance of smart logistics, its adoption in the textile industry is not without significant challenges. One of the most persistent barriers is the high cost of digital technologies and the uncertainty surrounding return on investment, particularly for small and medium-sized enterprises (SMEs). While large firms may have the financial resources to deploy end-to-end logistics automation, SMEs often struggle to justify such investments, especially in volatile markets. Another major challenge is data fragmentation caused by incompatible systems, supplier heterogeneity, and inconsistent data standards (Holly et al. 2023). This fragmentation hinders the development of a single, coherent view of supply chain performance and undermines efforts to implement predictive analytics or machine learning models.

Human capital limitations represent another critical barrier. The successful deployment of smart logistics systems requires a workforce that is digitally literate and capable of working with advanced analytics, sensor data, and cloud-based platforms. Many textile firms lack the internal capacity to manage these tools effectively and must rely on external consultants or technology providers (Sangaji, Setyaning, and Marsasi 2023). This dependence can lead to knowledge gaps and reduce long-term sustainability of digital initiatives. Moreover, organizational resistance to change—often rooted in a fear of job displacement or skepticism toward automation—can create cultural inertia that slows the pace of transformation.

Nevertheless, several enablers can facilitate the adoption of smart logistics in the textile sector. Government support in the form of digitalization grants, tax incentives, and training programs can significantly lower entry barriers. Collaborations with technology providers, universities, and research institutes offer opportunities for knowledge transfer and experimentation. Leadership commitment to digital transformation and clear communication of its benefits across all levels of the organization serve as critical internal enablers (Singh 2022).

## **THEORETICAL MODEL**

This model illustrates how smart logistics practices act as a central mechanism for supporting Industry 4.0 capabilities in the textile industry. The framework begins with the starting point of smart logistics implementation and divides the enabling factors into two primary streams: technological infrastructure (left side) and organizational readiness (right side). The technological side includes essential tools such as IoT-enabled tracking, RFID automation, automated warehousing, cloud-based platforms, AI-based analytics, and digital twin applications. These components collectively modernize logistics processes, allowing for real-time visibility, automation, and data-driven control across textile supply chains. Each of these innovations enhances operational precision, efficiency, and responsiveness, which are foundational to Industry 4.0 readiness.

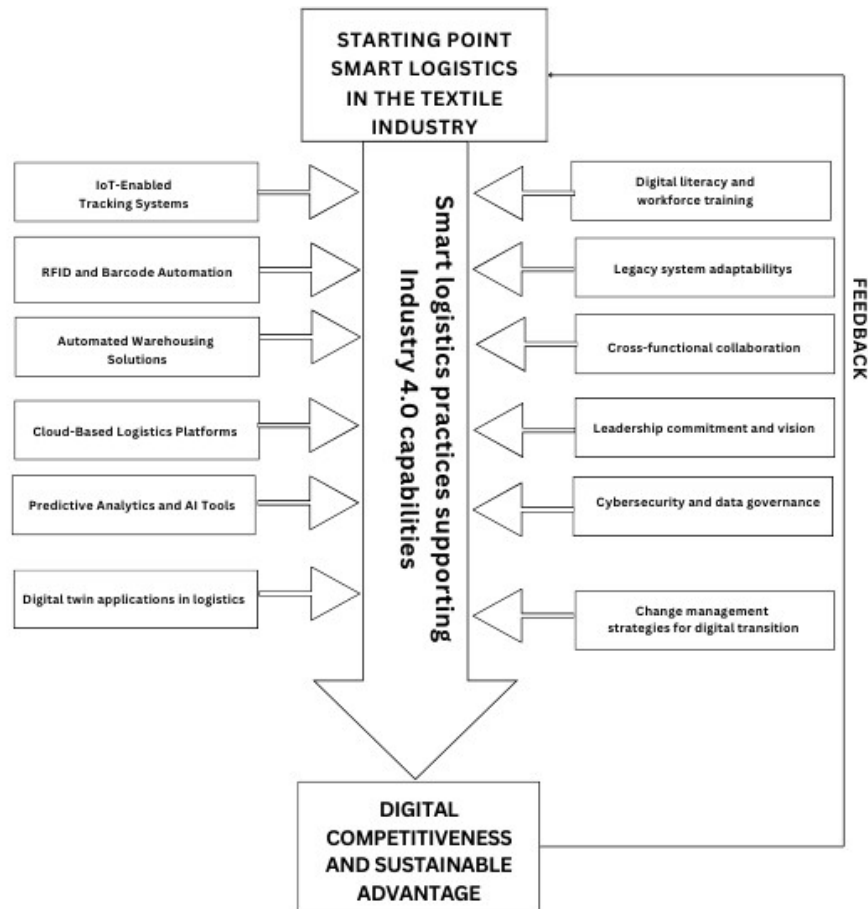


Figure 11 Theoretical model

On the organizational side, the model highlights critical enablers such as digital literacy, legacy system adaptability, cross-functional collaboration, leadership vision, cybersecurity, and change management strategies. These represent the human, structural, and strategic conditions needed to successfully implement and scale smart logistics solutions. As these inputs converge through the central pillar—smart logistics practices supporting Industry 4.0 capabilities—they lead to the emergence of digital competitiveness and sustainable advantage for textile firms. The feedback loop reinforces the idea that this transformation is iterative and should be continuously refined in response to performance metrics and evolving technological landscapes.

## CONCLUSION

The integration of smart logistics practices in the textile industry plays a critical role in supporting the transition toward Industry 4.0 capabilities. As the textile sector faces increasing pressure to become more responsive, sustainable, and digitally mature, logistics functions are evolving from traditional, operational roles into strategic enablers of digital transformation. Technologies such as IoT, RFID, cloud platforms, AI-driven analytics, and digital twins form the technological foundation that enables real-time visibility, automation, and predictive control across supply chains. These systems not only improve efficiency but also generate actionable insights that enhance responsiveness to volatile demand and shorter product life cycles, which are typical in textile manufacturing and retail.

Equally important are the organizational elements that determine whether these technologies can be effectively adopted and scaled. Workforce readiness, legacy infrastructure, internal collaboration, digital leadership, and secure data governance are essential components of a successful transformation strategy. Change management efforts, supported by clear vision and cross-functional alignment, help organizations overcome resistance and build long-term digital capability. The combined impact of these technological and organizational factors leads to improved customer responsiveness, increased resilience, more sustainable operations, and accelerated time-to-market. When smart logistics is positioned at the center of a firm's Industry 4.0 agenda, it enables not only digital integration but also strategic value creation that reinforces the textile industry's competitiveness in a digitally driven global economy.

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## **PROJECTING WORK CLOTHES FOR EMPLOYED IN TO THE COMPANY LINGLONG INTERNATIONAL**

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### **ABSTRACT**

This paper deals with the design of workwear for employees of Linglong International, with the aim of improving functionality, safety, and the visual identity of employees. The study is based on the analysis of existing solutions and the needs of workers in different production sectors, with special attention given to ergonomics, material selection, and working conditions.

The research methodology includes a literature review, observation of the working environment, and a comparative analysis of contemporary workwear solutions. Based on the collected data, design proposals were developed that meet occupational safety standards while also enhancing comfort and aesthetic appearance.

The results indicate that properly designed workwear can significantly contribute to increased employee efficiency, reduced risk of injuries, and strengthening of the company's corporate identity. In conclusion, the paper provides guidelines for further improvement of workwear design in an industrial environment.

**Key words:** workwear, ergonomics, occupational safety, design, industry, corporate identity.

### **INTRODUCTION**

Modern industrial production imposes high demands in terms of safety, functionality, and work organization, where workwear plays a significant role in employees' daily activities. In addition to serving as a basic form of occupational protection, workwear also affects comfort, productivity, and the visual identity of a company. In this context, proper design of workwear becomes an important factor in improving working conditions and overall business efficiency.

Linglong International, as a part of contemporary industry, requires tailored workwear solutions that correspond to specific working conditions and the needs of employees across different sectors. The analysis of existing models indicates the need for improvement in terms of ergonomics, material selection, as well as functional and aesthetic characteristics.

As part of this study, a detailed analysis of employee needs was conducted, based on which two workwear collections were designed and developed – one for office employees and the other for employees working in production facilities. These collections were created to meet the specific requirements of different job positions, ensuring that the conditions of functionality, safety, comfort, and representativeness are fulfilled for all roles and types of work.

The aim of this paper is to develop a workwear concept that meets modern occupational safety standards, improves employee comfort, and contributes to strengthening the company's corporate identity. The paper is based on the analysis of theoretical and practical aspects of workwear design, applying appropriate methodological approaches.

### **Inspiration**

The inspiration for designing the workwear originated from the analysis of contemporary trends in industrial design, as well as from the specific needs of employees at Linglong International. Special attention was given to functionality, ergonomics, and adaptability of the garments to different working conditions, while maintaining a professional and recognizable appearance.

The visual inspiration is based on a minimalist and modern design approach, with an emphasis on clean lines, simple forms, and clearly defined details. The color palette is aligned with the company's corporate identity, contributing to the visual consistency of employees.

In addition to aesthetic aspects, inspiration was also found in technical and innovative materials that ensure durability, protection, and comfort during work. By combining modern design approaches with functional requirements, solutions were developed that meet the needs of both office staff and employees working in production facilities.

### **Inspiration for the first Collection**

The inspiration for the first part of the collection is based on nature, soft tones, comfort, and ease. The main idea is to create a visually calm and harmonious design that reflects a balance between functionality and aesthetics. Nature, as the primary source of inspiration, is reflected in the use of soft, neutral, and pastel tones that bring a sense of lightness and tranquility to the working environment.

Special emphasis is placed on comfort and ease, ensuring that the clothing allows unrestricted movement and a pleasant feeling throughout the entire working day. Materials and cuts are carefully selected to follow the natural lines of the body and provide maximum practicality in everyday work. By combining natural motifs, soft color palettes, and functional design, a collection is created that contributes to a sense of relaxation, professionalism, and visual harmony.



*Figure 1: Inspiration for office employees at Ling long*

### **Inspiration for the second Collection (Production facilities)**

The inspiration for the second collection is based on a completely different rhythm dynamic, energetic, and aligned with the fast-paced nature of work in production facilities. Unlike the office collection, the focus here is on speed, mobility, and functionality, as production work requires garments that ensure safety, durability, and freedom of movement under demanding conditions.

The design concept is inspired by Formula 1, which represents speed, precision, and technical excellence. This influence is reflected in the choice of cuts, lines, and detailing, combining aerodynamic principles with practical and ergonomic solutions designed to support workers in active environments.

The collection incorporates bold and energetic color tones combined with contrasting elements that follow the rhythm of the production process, enhance visibility, and contribute to workplace safety. Materials are selected to be durable, lightweight, and adaptable, ensuring comfort and functionality throughout the working day. The result is workwear that not only meets safety and technical requirements but also visually reflects the energy and dynamism of production work, motivating employees and emphasizing efficiency and professionalism.



*Figure 2: Inspiration for Production facilities at Ling long*

**DESIGN OF THE FIRST COLLECTION FOR OFFICE EMPLOYEES AT LINGLONG INTERNATIONAL COMPANY**



*Figure 3: Collection for office employees at Ling long company*

### **DESIGN OF THE SECOND COLLECTION (PRODUCTION FACILITIES) FOR LINGLONG INTERNATIONAL COMPANY**

The second collection has a greater emphasis on practicality, comfort and functionality of the clothing. The models are urban and contemporary in dynamic colors to make workers more visible in factories where there are many modern machines and risks at work.



*Figure 4: Collection for production facilities at Ling long company*

The second collection, designed for employees in production facilities, focuses on functional and safe workwear tailored to the requirements of different job positions and tasks. The collection includes work overalls made from durable and comfortable materials, allowing unrestricted movement, long-term wear, and resistance to wear, while adapting to the dynamic work environment.

In addition to overalls, the collection features universal women’s jackets for the transitional period, designed to provide protection against changing weather conditions while maintaining comfort throughout the working day. The jackets include practical details such as pockets, zippers, and adjustable elements that facilitate work and provide flexibility for employee activities.

The color palette of the collection is vibrant and highly visible, enhancing employee safety in hazardous areas of production facilities, while also being aligned with the company’s visual identity. This creates an optimal combination of functionality, safety, and aesthetic appeal, meeting the needs of all job positions and tasks within the production environment.



*Figure 5: Collection for production facilities at Ling long company - Universal women's jacket*

## **CONCLUSION**

The aim of this study was to develop a workwear concept for employees at Linglong International, focusing on two collections: one for office staff and another for production facility employees. An analysis of employee needs, working conditions, and contemporary workwear design trends enabled the creation of solutions that combine functionality, safety, comfort, and aesthetic appeal.

The first collection, intended for office employees, focuses on elegance, professionalism, and visual harmony, using soft tones and materials that provide long-lasting comfort and freedom of movement. The second collection, for production facility staff, is based on dynamics and functionality, featuring work overalls and universal women's jackets for the transitional period, made from durable and adaptable materials. Vibrant colors and visible details enhance safety and reduce risks, while design elements align with the company's corporate identity.

The result of the research and design process is functional and aesthetically cohesive workwear that meets the needs of all positions and tasks within the company. This study demonstrates that thoughtfully designed workwear can significantly contribute to employee productivity, safety, and satisfaction, while simultaneously strengthening the company's visual identity.

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## **TOWARD A CIRCULAR AND COMPETITIVE TEXTILE SECTOR: LINKING INDUSTRY 4.0 AND SUSTAINABLE SUPPLY CHAIN MANAGEMENT**

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### **ABSTRACT**

*This paper explores how Industry 4.0 technologies support sustainable supply chain management (SSCM) in the textile industry. The sector faces major environmental and operational issues such as high energy use, waste generation, and inefficient logistics. Integrating digital tools like the Internet of Things (IoT), Artificial Intelligence (AI), and Blockchain enables real-time monitoring, data-based decision-making, and greater transparency. The paper reviews studies linking Industry 4.0 and sustainability, showing how these technologies foster circular economy goals by optimizing resources, reducing waste, and improving product traceability. It concludes that merging SSCM and Industry 4.0 promotes eco-efficient and competitive textile production. However, barriers such as high investment costs, digital skill gaps, and fragmented supply networks limit broader implementation. The study highlights that advancing digital and sustainable transformation in the textile sector depends on strong collaboration among governments, businesses, and education.*

**Key words:** Industry 4.0, Sustainable supply chain management, Textile industry, Circular economy, Digital transformation

### **INTRODUCTION**

The textile industry is one of the most resource demanding and environmentally impacting economic sectors in the world. Featured by high use of water and energy, high consumption of chemicals, and large waste flows, the sector is under growing pressure to turn more circular and sustainable (European Environment Agency, 2025). Emissions from textile and apparel are estimated to account for approximately 8% - 10% of global greenhouse-gas emissions (IFC, 2023). Therefore, innovative solutions that incorporate an environmental, economic and technological point of view have become essential for the transformation of the textile sector. At the European level, the EU Circular Economy Action Plan (2020) singles out textiles as a priority value chain for redesign toward durability, reuse and recyclability, and the EU Strategy for Sustainable and Circular Textiles (2022) sets a vision that by 2030 all textile products placed on the EU market are durable and produced in fair and sustainable conditions. On the national level, Serbia, too, as a candidate country, has taken cognizance of these processes: the country's Smart Specialization Strategy 2020–2027 identifies the textile industry as a key area for technological change and sustainability, while the 2022–2024 Circular Economy Development Programme provides concrete measures for eco-innovation and digitalization. Aligned with this, the emergence of Industry 4.0 technologies, including the Internet of Things (IoT), AI, blockchain, and advanced data analytics, have already shifted how industries pursue sustainability and efficiency (Khurshid, 2024). These technologies, when combined with SSCM, provide support for digital traceability, predictive maintenance, and optimization of resource use in enabling circular economy objectives (Ali et al., 2024). Yet challenges remain in that there is uneven readiness for such technologies, there are high costs of investment involved, and the standards are still evolving (Nobre, 2023). This paper examines how the convergence of SSCM and Industry 4.0 technologies can drive the transformation of the textile industry toward circularity and competitiveness in the long term.

Based on a comprehensive literature review, the study identifies key patterns, strengths and weaknesses in the integration of technological and management practices. It begins with global challenges in the textile industry and briefly reviews EU and Serbian policy frameworks. It then examines how Industry 4.0 can improve sustainable supply chain management and ends with policy and managerial recommendations for building a circular and competitive textile sector.

## **METHODOLOGY**

The subject of this research is the integration of sustainable supply chain management and Industry 4.0 technologies in the textile industry. The core problem lies in the limited application of sustainable and digital practices in textile production, which continues to rely on linear models that generate excessive waste and environmental pollution. Many companies lack technological infrastructure, strategic planning, and awareness of the benefits that digital transformation can bring to sustainability and competitiveness.

### **Research goal**

The goal of this research is to analyze how the combination of sustainable supply chain management and Industry 4.0 technologies can contribute to the development of a circular and competitive textile industry. The paper aims to identify the main opportunities, challenges, and directions for improving sustainability through technological innovation and strategic integration.

### **Research question**

Based on the defined problem and research goal, the following research questions have been formulated:

RQ1: How can Industry 4.0 technologies enhance sustainable supply chain management in the textile industry?

RQ2: In what ways can the integration of sustainability and digitalization accelerate the transition **toward a circular economy and improve competitiveness?**

### **Research method**

This study is based on a theoretical approach that includes literature review, analysis, synthesis, and deduction. The research examines academic and professional sources, evaluates their findings, and compares results to identify common trends and best practices. Through this approach, the study provides a structured understanding of how sustainable and digital strategies can jointly transform the textile sector.

## **THEORETICAL FRAMEWORK AND LITERATURE REVIEW**

The combination of Sustainable Supply Chain Management (SSCM) and Industry 4.0 technologies in the textile industry is part of a wider transformation toward circular and low-carbon production. This transformation is not only about introducing new technologies but also about changing the way companies learn, how institutions create supportive rules, and how businesses redefine value creation in a sustainable way. When we talk about these changes we can identify three main theories that help explain this action of change: the socio – technical transition theory, institutional theory, and the dynamic capabilities theory. The socio – technical transition theory explains that large industrial changes happen one at the time through the interaction of technology, user behavior, policies, and culture (Ramirez, 2021).. In the textile sector, this means that sustainability goals, European Union regulations, and growing consumer consciousness are impelling companies to use modern digital

tools. These modern technologies not only improve production efficiency but also secures transparency and cooperation in every part of the supply chain (Zhang, 2023). The other theory, the institutional theory focuses on external factors. More specifically on how external factors such as laws, standards, and social expectation influence business behavior.

Examples for this theory is the EU Circular Economy Action Plan (2020) and the EU Strategy for Sustainable and Circular Textiles (2022). These programs encourage companies to adopt sustainable practices and methods (Mariam et al., 2023). In Serbia, similar programs are supported by the Smart Specialization Strategy (2020–2027) and the Circular Economy Development Programme (2022–2024). However, not all companies respond in the same way. Bigger companies usually have the resources and knowledge to implement digital solutions, while small and medium-sized companies often face challenges such as high costs, lack of skills, or insufficient infrastructure. In order to make the digital transition more inclusive, institutions need to provide training, financial assistance, and partnerships. Which are the first steps for ensuring a circular economy working pattern. The third theory is the dynamic capabilities theory. This theory looks inside the company and explains how firms develop the ability to adapt reorganize their processes when the environment changes (Ortiz-Avram, 2024). In the textile manufacturing, this can be recognized in the use of digital tools like the already mentioned IoT, monitoring and AI – based planning to track energy usage, waste reduction and the improvement of the decision – making (Lu, Zhao & Liu, 2022). Overall, these theories show that the transformation of the textile industry toward sustainability happens at several levels, which all have a synergic operation. At the micro level, individual companies adopt and use digital tools to improve performance. At the meso level, supply chains coordinate information and materials more effectively. At the macro level, institutions and policies guide the overall shift toward a circular economy. Sustainability in the textile industry does not depend only on technology but on the interaction between people, companies, and institutions. When these elements work together, they create a system that supports innovation, responsibility, and long-term competitiveness.

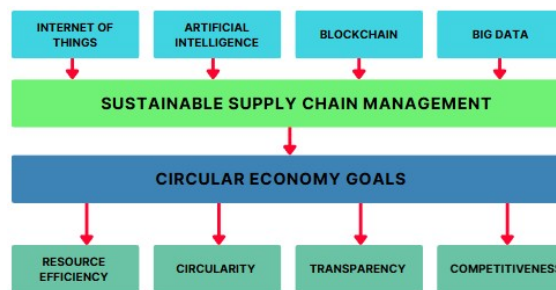
## RESULTS AND DISCUSION

Particular empirical studies highlight how digital technologies are transforming sustainable supply chain management (SSCM) in the textile industry. One clear pattern can be seen in the use of blockchain to ensure full material traceability across fiber networks, as demonstrated by Lenzing’s case study (Ahmed & MacCarthy, 2021). Another example comes from process improvements at the production level, where digital control systems and process technologies help companies monitor and reduce their environmental impact (Zhang, Lei, Feng, Chang & Ye, 2020). In addition, the growing use of IoT-based monitoring allows textile manufacturers to collect real-time data, improve compliance, and increase resource efficiency throughout their operations. These examples show that technological success in the textile industry depends not only on innovation itself but also on how data practices, collaboration among partners, and institutional support are developed and managed (Badhwar, Islam & Tan, 2023). The first of these patterns, examines the fiber producer Lenzing company. This Austrian company developed and implemented the **TextileGenesis™** blockchain platform to make the whole supply chain more transparent and to increase traceability. This system is used for fibers such as the **TENCEL™** and **LENZING™ ECOVERO™**, which are made from sustainably sourced wood pulp. Through its **Fibercoin™** technology, Lenzing creates **digital tokens** for every physical shipment of these fibers. The tokens work like a digital certificate, recorded on the blockchain, a secure online ledger that cannot be changed once it is uploaded. This digital “fingerprint” follows the fiber as it moves from production to spinners, mills, and fashion brands, ensuring that materials remain authentic and sustainably sourced (Lenzing AG, 2020). A study published by **Ahmed and MacCarthy (2021)** analyzed this case and confirmed that blockchain enables products to be authenticated and sustainability claims to be verified at every stage of the textile production chain. They also explained that technology alone does not guarantee transparency, which is crucial for the circular economy. What also really matters are the rules about the system,

moreover how the system is used, who is allowed to manage and add data, who can see it and how detailed the information is. When all the data of the supply chain is stored on the blockchain, and can be independently verified, it allows the possibility to check whether sustainability claims are true. This stops companies from overstating their environmental efforts (“greenwashing”) and supports the European Union’s move toward a circular economy, where materials are traceable, responsibly used, and reused in a transparent way. The second case study shows the **Zhongshan Yida Textile Co., Ltd.**, a major denim manufacturer in **Guangdong Province, China**, who implemented a large-scale **wastewater treatment system modification** to reduce its environmental footprint. They initially used a conventional biological treatment system, where bacteria break down organic waste in the water.

They replaced the plant with a combined membrane bioreactor (MBR) and a reverse osmosis (RO) process. In this configuration the MBR perform a biological oxidation and membrane filtration to remove suspended solids, color and organic pollutants. Then the RO unit further filters and purifies the water again to remove dissolved salts and very small particles. This two-step process allows the plant to produce much cleaner water than before. So according to the findings, the plant achieved significant improvements in wastewater quality after the system upgrade (Zhang et al. 2021). The chemical oxygen demand (COD) which shows how polluted the water is, dropped from about **180 mg/L to below 50 mg/L**. The color of the water was reduced by more than 95%, and the **conductivity reached below 100  $\mu$ S/cm** meaning the treated water was almost as clean as tap water. With this the system’s performance consistently met the requirements of **China’s national “Discharge Standards of Water Pollutants for Dyeing and Finishing of the Textile Industry” (GB 4287-2012)**. Although this upgrade and system is mainly connected to environmental engineering improvement, it also serves as an example of digital sustainable supply chain management. The MBR and RO system constantly monitors key parameters, such as flow rate and conductivity all managed through a **programmable logic controller (PLC) - based data-acquisition system**. This digital control enables the factory to track and record its water-reuse performance in real time, feeding verified environmental data into **brand sustainability dashboards** and **regulatory compliance reports**. This case shows when combining technology, digital monitoring and environmental standards it creates the socio - technical foundation necessary for credible SSCM practices. With this said, in the context of the textile industry, this example displays that sustainable supply chain management is not just about choosing suppliers or transporting materials. It also includes using modern technologies, digital solutions for monitoring production processes that can save the water, reduce pollution and help the company be more sustainable in all the processes. With these technologies and operational improvements, textile companies can create a more efficient and transparent supply chain. The third examples of digital transformation for sustainability in the textile industry is presented in a recent case study by Petrillo, Rehman, and Baffo (2024). The research shows the implementation of an Internet of things (IoT) based monitoring system in medium - sized textile manufacturing plant in Faisalabad, Pakistan. Their system integrated a network of sensors, including sensors for temperature measurement (LM35), humidity sensors (DHT22), also ultrasonic sensors which measure the level of water in tanks which are used for washing or dyeing textiles, and RPM sensors that measure the rotation speed of machines used to check efficiency or detect issues. These sensors are all linked to a centralized gateway and a remote graphical interface for continuous environmental and operational monitoring (Petrillo et al., 2024). When an irregularity occurred, like a rise in the temperature or abnormal water consumption, the system automatically alerts, enabling workers to react quickly and prevent inefficiencies. The authors state that the IoT retrofit greatly improved real-time monitoring of energy and environmental parameters, helping meet sustainability standards and reducing manual measurement errors. The system also stores data which can be analyzed to identify long - term trends and to use resource more efficiently. From a SSCM perspective this case shows that even small and medium - sized companies can use affordable digital technologies and solutions to make operations more transparent. Despite limited technical and financial capacity, the company managed to implement a functional data infrastructure that supports environmental reporting and aligns with circular economy goals. The figure conceptually illustrates the interaction

between Industry 4.0 technologies and Sustainable Supply Chain Management (SSCM) within the textile sector. It visualizes how smart digital infrastructures - comprising IoT sensors, Artificial Intelligence, Blockchain networks, and data-analytics platforms - connect every stage of the textile value chain, from raw-material sourcing to production, distribution, and end-of-life recovery. Through continuous data exchange, these technologies enable real-time monitoring, predictive maintenance, and closed-loop material flows, which are essential for circular-economy performance. The central part of the figure represents the integration layer where digital data supports sustainability indicators such as energy efficiency, waste reduction, and traceability. Arrows between industry actors illustrate collaborative feedback loops linking suppliers, manufacturers, retailers, and consumers. Institutional and policy frameworks, positioned at the outer level, show how governments, education, and industry alliances provide the governance and knowledge base required for digital-sustainable transformation. Altogether, the diagram communicates that competitiveness and environmental responsibility in the textile industry emerge when technological innovation, management practices, and institutional support operate in synergy.



*Figure 1. Integration model of Industry 4.0 technologies and Sustainable Supply Chain Management (SSCM) in the textile industry, source: author*

The figure conceptually illustrates the interaction between Industry 4.0 technologies and Sustainable Supply Chain Management (SSCM) within the textile sector. It visualizes how smart digital infrastructures - comprising IoT sensors, Artificial Intelligence, Blockchain networks, and data-analytics platforms - connect every stage of the textile value chain, from raw-material sourcing to production, distribution, and end-of-life recovery. Through continuous data exchange, these technologies enable real-time monitoring, predictive maintenance, and closed-loop material flows, which are essential for circular-economy performance. The central part of the figure represents the integration layer where digital data supports sustainability indicators such as energy efficiency, waste reduction, and traceability. Arrows between industry actors illustrate collaborative feedback loops linking suppliers, manufacturers, retailers, and consumers. Institutional and policy frameworks, positioned at the outer level, show how governments, education, and industry alliances provide the governance and knowledge base required for digital-sustainable transformation. Altogether, the diagram communicates that competitiveness and environmental responsibility in the textile industry emerge when technological innovation, management practices, and institutional support operate in synergy.

## CONCLUSION

This research reviewed how the integration SSCM and Industry 4.0 technologies can drive the textile industry towards significant circularity, environmental responsibility, and competitiveness. The analysis of international case studies, like the Lenzing’s blockchain traceability system, Zhongshan Yida’s digitally monitored wastewater treatment, and the IoT-based retrofit implemented in a Pakistani textile factory substantiated that digital technologies are powerful enablers of sustainability

when implemented in coherent management strategies and institutional frameworks. Aligning with RQ1 the findings show that the Industry 4.0 technologies help enhance SSCM firstly through three mechanisms: real - time monitoring of operational and environmental parameters via IoT systems, then traceability and data integration with blockchain systems, and resource efficiency. These tools reduce uncertainty, improve decision - making, and provide transparent, measurable, and adaptive supply chains. Interestingly, the results indicate that technology alone is insufficient, organizational competencies, workforce competencies, and governance structures are also vital in achieving sustainable benefits. Concerning RQ2, the study finds that the integration of digitalization and sustainability acts as a facilitator for circular economy transition by allowing *closed-loop material flows, energy efficiency, and data-driven compliance reporting*. Companies that implement digital tools such as IoT, blockchain and smart sensors make it possible to collect and analyze data in real time, which help textile companies to use materials more efficiently and also to reduce waste which is the core for circular economy. Also these technologies follow environmental standards and report their results constantly not just to estimate. The research also acknowledges the persistent barriers to widespread adoption, particularly among small and medium sized enterprises. Financial constraints, limited technical expertise, and lack of interoperability standards remain key challenges. Policy measures like training, funding, and partnerships are key for a fair digital-sustainability transition. In Serbia, the Smart Specialization Strategy and the Circular Economy Programme support this alignment with EU goals. In conclusion the study confirms that integrating Industry 4.0 technologies into SSCM practices enhances both sustainability and competitiveness in textile supply chains. However, limited data availability and uneven technological readiness remain major barriers. Future research should focus on developing measurable frameworks for circular performance and digital maturity assessment in textile SMEs.

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## CIRCULAR ECONOMY IN CLOTHING AND TEXTILE INDUSTRIES

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### ABSTRACT

*The paper points out that the mass production of textiles leads to an increasing amount of textile waste. Clothes in the concept of fast fashion are designed for single use. This encourages unnecessary and excessive consumption and thus creates large amounts of waste. In the existing design of textile products, most products cannot be recycled in a financially justified way. Worldwide, approximately 25 to 40% of all used textile products become waste. On the other hand, the technological process of textile production consumes huge amounts of water, land and raw materials. The paper discusses textile waste, which today is most often classified as biodegradable. However, the paper points out that this classification is not justified. A large part of textile waste is biologically poorly degradable, such as: synthetic fibers, wool, surface-treated textile materials, fibers supplemented with composites, etc. The fact is that today the disposal of textile waste in landfills is increasingly limited. On the other hand, burning textile waste produces harmful gases for the environment. Therefore, the paper notes that more and more attention should be paid to the life cycle of textile products, which can be observed in the following phases: the production phase, the use phase and the phase after the use of the clothing, i.e. the phase of the end of the product's life. A comprehensive analysis of the product's life cycle can lead to the best solutions for applying the circular economy.*

**Key words:** circular economy, product life, textile waste, recycling

### 1. INTRODUCTION

Today, the textile industry is at the very top of the largest producers of waste. Namely, in the textile industry, around 40 million tons of textile waste is generated annually on a global level. There is no viable solution for this waste today. Thus, most of this waste is sent to landfills or incinerated today. On the other hand, the technological process of textile production consumes huge amounts of water, land and raw materials. Therefore, serious efforts are being made to shift from a linear economy to a closed-loop circular economy. [1]

The circular economy is a model of production and consumption that involves selling, using, reusing, repairing, restoring and recycling existing products and materials as long as possible. In this way, the lifetime of each product is extended. In practice, this leads to the reduction of waste to the smallest possible extent. When a product reaches the end of its life, the materials from which it was made are, whenever possible, recycled. They can be used over and over again, creating added value. This leaves the traditional linear model in which products are thrown away after use. Such a model requires large amounts of cheap materials and energy. [2]

### 2. CIRCULAR ECONOMY

A circular economy is a system which maintains the value of products, materials and resources in the economy for as long as possible, and minimises the generation of waste. This means a system where products are reused, repaired, remanufactured or recycled.

Actions on the circular economy also contribute to other key EU priorities, including a green recovery, climate mitigation and energy savings, biodiversity protection, and global efforts on sustainable development. [3]

In 2015, the European Commission adopted an ambitious circular economy action plan. It announced 54 measures along the entire lifecycle of products to accelerate EU's transition towards a circular economy. All these measures have been adopted.

Amongst other measures, revised EU legislation on waste entered into force in 2018. It set out clear recycling targets and a long-term plan for modern waste management. This included: [3]

- ❖ targets for recycling of municipal and packaging waste;
- ❖ binding targets to reduce landfill to a maximum limit;
- ❖ measures to reduce food waste and marine litter.

Also in 2018 there were further initiatives such as an EU strategy on plastics, a report on critical raw materials in the circular economy, rules on single-use plastics and proposed legislation on minimum requirements for water reuse (adopted in 2020). [3]

In March 2020, as a core building block of its 2019 European Green Deal to boost the efficient use of resources by moving to a clean, circular economy, restore biodiversity and cut pollution, the Commission adopted a new circular economy action plan for the EU. This includes measures to:

- ❖ make sustainable products the norm in the EU;
- ❖ give more power to consumers and public buyers;
- ❖ focus on the sectors that use most resources and where the potential for circularity is high, such as:
  - ❖ electronics and ICT,
  - ❖ batteries and vehicles,
  - ❖ packaging, plastics and textiles,
  - ❖ construction and buildings,
  - ❖ food, water and nutrients;
- ❖ ensure less waste;
- ❖ make the circular economy work for people, regions and cities;
- ❖ lead global efforts on circular economy. [3]

### **3. ADVANTAGES OF THE CIRCULAR ECONOMY**

The transition to a circular economy greatly affects the protection of the environment. Namely, the reuse and recycling of products reduces the use of natural resources, reducing the destruction of habitats and the loss of biodiversity. The circular economy also makes a significant contribution in terms of reducing greenhouse gas emissions. The circular economy contributes to the production of efficient and sustainable products. This helps to reduce the consumption of energy and resources. This is because the design phase of a product is considered to be responsible for more than 80 percent of its environmental impact. The circular economy also goes in the direction of solving packaging, which is becoming an ever-increasing problem. On average, each European produces around 190 kilograms of packaging waste per year. The aim of the circular economy is to solve the problem of unnecessary packaging and improve its design to promote reuse and recycling. The circular economy wants to contribute to reducing dependence on raw materials. The world's population is growing, and so is the demand for raw materials, although the supply chain is limited. Limited supplies also mean that some EU countries are dependent on raw materials from other countries. According to Eurostat data, each European used 14.9 tons of raw materials in 2022. The total value of trade (import and export) of raw materials between the European Union and the rest of the world in 2023 was 165 billion euros. The circular economy aims to improve the recycling of raw materials, which would reduce risks in supply, such as price volatility, availability and dependence on imports. This particularly applies to critical raw materials needed to produce technologies key to achieving climate goals, such as batteries and electric motors. The circular economy tends to create new jobs and save money. Namely, the introduction of circular economy principles increases competitiveness, stimulates innovation and economic growth and creates new jobs. Redesigning materials and products for circular use also stimulates innovation in different sectors of the economy. This gives consumers a long-lasting and innovative product and saves money in the long run. Therefore, today the whole world tends to introduce new measures to reduce waste and increase the sustainability of products. These measures

mainly include eco-design, packaging, manipulative green marketing, right to repair, waste management and other key areas. [2]

#### 4. ANALYSIS OF WASTE MANAGEMENT AND RECYCLING

The subject of waste management and recycling is dealt with by the EU Commission. [4] According to their report, the industrial and manufacturing sector was investigated to a small extent (11%). [5] This indicates that there is room for future research in this sector. However, publications that assess the recycling of industrial waste are assigned to the waste management sector in the analysis of the aforementioned report. This is shown in Figure 1. Figure 1 shows that the agriculture and food systems sector is another area with a relatively small number of publications (9%). There is also an overlap with waste management in this research, as studies examining food waste, food waste prevention and recycling of agricultural and food waste are categorized into the waste management and recycling sector.



Figure 1: Thematic focus of research in the waste management sector [5]

The global trend of "fast fashion" leads to the mass production of cheap clothes to meet the needs of the market. From 2000 to 2015, clothing production almost doubled globally. A large amount of clothing that reaches the market consists of inexpensive clothing products that average \$5 to \$10 and whose quality matches the price at which they are sold. [6]

Most often, it is about products made of synthetic fibers and with a small percentage of natural fibers. The trend in Western countries is to throw away clothes after only two or three uses. America is the largest exporter of textile waste, which consists of slightly used clothing. The clothes they export are bought by poor countries in order to resell them to thrift stores for a few dozen cents.

The large amount of clothing that remains is of poor quality and is not wanted even by charities that supply poor and vulnerable populations with clothing. It is estimated that in Great Britain, which is the second largest exporter of used textiles after the USA, over 13 million items of clothing are thrown away in just one week. Most textile waste from Western countries ends up in the Atacama Desert in Chile. Every year, 39,000 tons of textile waste are dumped in this desert. On average, the amount of textile waste dumped in this desert is equivalent to one full truckload of waste every second and takes at least 200 years to decompose. [7]

According to current European EU regulations, all textile waste is classified as biodegradable, but such classification is only partially justified. In most cases, only cellulosic fibers (cotton, jute, ramie, flax, hemp...) are easily biodegradable, but in order to be completely biodegradable, they must not be excessively treated with various surface polymers. [8]

Almost all polymer fibers are slightly biodegradable (polyamide, polyester, polyurethane, polypropylene, PVC, elastane, ...). Given that a large percentage of clothing products that fall into the

"fast fashion" category are made of synthetic fibers, and cellulose fibers are represented in a much smaller percentage, it would be more objective to classify all textile waste as poorly biodegradable. Given that polyester, which is the cheapest fiber and also the most represented in "fast fashion", is obtained on the basis of petroleum, like plastic, by mixing ethylene glycol with dimethyl terephthalate, and after their reaction at high temperatures and air, a polymer is formed that takes at least 200 years to decompose. This is where the special problem of microplastics arises. Microplastic is a small piece of plastic, usually much smaller than 5 mm. Increasing amounts of microplastics are found in the environment, including the sea and soil, as well as food and drinking water. Microplastics do not degrade and usually accumulate in the environment. Unless, in rare cases, it is not specifically designed for biodegradation in the open environment. Biodegradability is a complex phenomenon, especially in the marine environment. There is growing concern about the presence of microplastics in various parts of the environment, its impact on the environment and biodiversity, and potentially on human health. [1,7]



Figure 2: Discarded textile waste

Therefore, to a large extent, there are initiatives to combat microplastic pollution, promote research and innovation, and ensure integrated monitoring of microplastics. Namely, every time clothes made of polyester, rayon and nylon are washed, small parts of microplastics go into the water. Clothes made of synthetic materials, which are washed in washing machines, are responsible for 35% of primary microplastics released into the environment. One wash of PES clothing can release 700,000 microfibers that can end up in the human food chain. These tiny plastic particles eventually end up in the sea where they are eaten by plankton, then fish eat the plankton, and then fish that are used for food end up in human bodies. Most microplastics from textiles are released during the first few washes, and fast fashion, due to its mass production, low prices and high volume sales, is responsible for many first washes. It is estimated that around half a million tons of microplastics come from synthetic clothing. This is equivalent to about 50 billion plastic bottles.[9]

In the world, numerous researches are funded to solve the problem of microplastics. However, it is clear that microplastics released from textiles have a measurable impact on the environment. Therefore, we are moving towards solving this problem. Especially in cases of unintentional release of microplastics into the environment. [1]

## **5. PRODUCT LIFE CYCLE**

In recent years, the circular economy has developed as a concept. That concept today goes beyond basic waste management and thus moves away from the traditional linear model. This means that the circular economy increasingly represents a systemic approach to extending the life of materials, maintaining higher quality, as well as contributing to solutions for the triple planetary crisis of climate

change, loss of biodiversity and pollution. Although today, in most cases, the circular economy focuses on avoiding the negative impacts of supply chains on the environment through changes within the economic system. In doing so, technological solutions are often emphasized. The circular economy is often portrayed as a techno-economic approach that prioritizes industrial strategies and economic growth alongside environmental goals. Life cycle assessment is important in this regard. This assessment is a standardized method (ISO, 2006, 2006a) designed to systematically quantify the environmental impacts of a product, process or service throughout its life cycle. The strength of life cycle assessment lies in its level of detail, comprehensiveness, quantitative nature and convenience as a comparative tool. [4]

The life cycle of textile products can be observed according to the following phases: production phase, use phase and phase after the use of clothing, i.e. the phase of the end of the product's life. The industrial production of textile products begins with the procurement of raw materials. It then continues through the processes of spinning, weaving, knitting, confectioning and refining until the assembly of the final product. The production of textile products is a complex process and therefore it is difficult to make a comprehensive overview of the overall impact of that process on the environment. [10,11]

The design of new textile products includes quality assurance throughout its entire life cycle. This includes all activities starting from design, projecting, production, distribution, use, maintenance, up to its recycling or disposal. Today, these activities are directed towards the development of new solutions for better recycling and management of waste material. For a typical textile product, there are seven life stages that it goes through: [12,13]

- ❖ concept and design stages: quality parameters of raw materials, parameters of use and maintenance of the end product, prediction and simulation of its possibilities, comfort and satisfaction of standards and legal provisions,
- ❖ engineering phases: include innovative tools for optimizing quality and ecology in production, distribution, application, use, service activities, recycling or disposal, and prototyping. This phase is based on the experiences of using existing products,
- ❖ production phases: include specification of materials in production, quality management, system management of errors / damage to materials, self-optimization of production systems, on-line control of quality and environmental parameters,
- ❖ distribution and application phases: envisage improvement in product quality standardization and quality data management,
- ❖ phases of use and service activities (dry cleaning and washing): envisage the development of methods and processes for retaining and restoring the functional properties of textile materials, the durability of properties during the phase of use, the development of new products that affect the improvement of product quality during the phase of use and care, instructions and training for the correct global use and care of products, analysis of problems arising during application and complaints, methods of more precise determination of possible errors, development of non-destructive methods for assessing quality, modeling / simulating the aging process in various conditions of use or care,
- ❖ phases of the second life cycle (reuse): envisage the development of new procedures by which existing textile products could be reused,
- ❖ end-of-cycle phases (recycling or disposal): foresee research in the last cycle that must be focused on development of new recycling procedures. [10]

The global textile value chain disproportionately burdens workers and communities in low- and middle-income countries, particularly through environmental pollution, poor textile waste management and poor working conditions. While focusing on individual (consumer) efforts and technology-driven solutions, the global need for systemic value chain change is often overlooked. Marginalized groups include women, migrant workers and local communities in the Global South, whose needs need to be met, fair wages achieved and social stigmas surrounding second-hand

clothing and repair practices addressed, and cultural differences in approaches to sustainability understood.

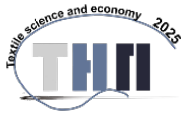
The value chain assessment clearly shows that comprehensive measures are needed at every stage of the value chain to ensure a fair and sustainable transition to a circular economy. Circular economy policies and strategies can have a huge impact on different regions, social systems and groups - emphasizing their need.

## 6. CONCLUSION

The mass production of textiles leads to an increasing amount of textile waste. Clothes in the concept of fast fashion are designed for single use. This encourages unnecessary and excessive consumption and thus creates large amounts of waste. In the existing design of textile products, most products cannot be recycled in a financially justified way. Worldwide, approximately 25 to 40% of all used textile products become waste. On the other hand, the technological process of textile production consumes huge amounts of water, land and raw materials. Therefore, the textile sector is the third largest source of water degradation and land use in 2020. Today, less than 50% of worn clothing is recycled or reused. Of that, only 1% is recycled (returned) into new clothes. Therefore, there are fewer and fewer areas on our planet that man has not contaminated with his waste. When an article of clothing is no longer needed, that article of clothing is most often disposed of in a landfill where it is left to long-term biodegradation that will last for the next 200 years. Another option is to recycle the garment and make new textile products from it, and the third option is to burn it with other textile waste, which leads to additional pollution of our planet. Of all the three options, only recycling is environmentally friendly if it is to allow new generations to come to have an ecosystem that is not destroyed and contaminated by waste that is a direct result of overproduction and little interest of responsible governments of large countries to deal with this very important problem. [14]

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## SELECTION OF NATURAL MATERIALS IN ETHNO APPLICATION FROM THE ASPECT OF ENVIRONMENTAL IMPACT THROUGH LCA

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### ABSTRACT

Tradition is defined as the heritage of values passed down from generation to generation. The ethno bag, as a heritage product necessary and adapted for everyday, multifunctional use—has once again gained the interest of the female population. The use of natural materials indicates concern for environmental protection (reducing pollution) and the concept of sustainable development. Sustainable development in the textile industry directs efforts toward cleaner technologies and includes rational consumption of natural resources, their renewal, and the reuse of natural materials throughout the product life cycle.

The selection of natural materials for an ethno bag (wool, cotton, wood) aims at a sustainable product with minimal negative environmental impact throughout all life cycle phases (lower overall ecological footprint), taking into account the possibility of reuse and recycling. The circulation of products through the life cycle directly affects waste reduction, CO<sub>2</sub> emissions, water consumption, and energy use. The choice of recyclable fabrics not only preserves family heritage but also contributes to sustainability.

**Key words:** Natural materials, Product life cycle, Technological processes, Product sustainability, Environmental impact.

### INTRODUCTION

It is considered that the selection of natural materials contributes to reducing negative environmental impacts. Environmentally friendly products demonstrate the necessity and justification of not polluting the environment during their lifetime. Thinking in terms of the product life cycle, with the ultimate goal of monitoring all its phases, primarily represents a comprehensive process of tracking material flows and their environmental impact.

The ethno bag is a product necessary and adapted for everyday multifunctional use. The choice of materials, as well as the production method, significantly affect the environment. Life cycle analysis of a traditional product made of natural materials wool fabric, cotton lining, and a wooden button as a decorative detail indicates the environmental impact of each life cycle phase, from raw material production to the end of the product's life (reuse or disposal in a landfill).

The aim of this paper is to present a “modernized” traditional product that has attracted interest and acceptance among the female population, especially younger women. A comparison is made between products of our grandmothers and those of today's young women, with a focus on material type, production method, and fabric pattern. In some cases, the visual identity of a product influences emotions during selection and purchase.

### NATURAL MATERIALS AND RAW MATERIALS IN ETHNO APPLICATION

Natural materials are traditionally considered one of the most important sources of natural wealth, creating new value in products necessary for humans. They are used directly or indirectly, usually requiring some form of processing (Milutinović, 2020).

Ecological materials (eco-materials) are recognized not only as a trend in clothing and modern design but also as the result of developing environmental awareness among consumers and, more importantly, producers and industries, which form the foundation of environmental preservation (Zrnić & Milošević, 2012; Frfulanović-Šomodi & Savić, 2019).

Eco-materials harm the environment only to an acceptable level throughout all product life cycle phases: raw material extraction, production, packaging, distribution, use, and disposal. Resource use (energy and materials) is minimized, recyclable materials are applied, and waste generation is reduced, supporting sustainable development (Malbaša, 2020). This reflects the interdependence of economy, society, and environment the three pillars of sustainability (Ristić & Pavlović, 2022). Modern trends emphasize product reuse rather than recycling whenever possible.

### **PRODUCTION OF THE ETHNO BAG**

There is a growing trend toward environmentally friendly materials in production. Many brands increasingly use materials such as organic cotton, bamboo, hemp, and other biodegradable and recyclable materials.

The ethno bag, a traditional multifunctional product from our grandmothers' time (Figure 1), is once again in trend. The idea of “returning to heritage” has evoked emotions and renewed interest among women. A comparison between past and present products highlights similarities in materials, production methods, and fabric patterns, while the visual identity often influences purchasing decisions.



*Figure 1: Ethno bag from our grandmothers' period*

An innovative version of the ethno bag (Figure 2) is presented, using the same material (wool fabric), similar production methods, and slightly modified fabric patterns. To protect the environment and reduce textile waste, the lining is made from recycled material. Specifically, it is produced from a reused cotton shirt that meets quality and functional requirements.



*Figure 2: Innovative version of the ethno bag*

Reviving traditional production is achieved through education on natural materials and raising consumer awareness, as well as organizing workshops. Recycled natural materials are becoming increasingly popular as alternatives to traditional fabrics. Sustainable design is also promoted, focusing on durability, quality, and multifunctionality.

The textile industry requires regenerative systems, reduced waste, lower resource and water consumption, energy efficiency, and renewable energy use (Köhler et al., 2021).

The main material is wool, processed through shearing, cleaning, washing, drying, spinning, and weaving into fabric used for bag production (Vilumsone-Nemes, 2012). Auxiliary materials include cotton lining and a wooden button. The lining is made from reconstructed garments, reintroduced into the life cycle instead of being discarded. The wooden button reduces plastic use and enhances recyclability.

The technological process includes input components (raw materials) and output (finished product), with production phases illustrated in Figure 3.

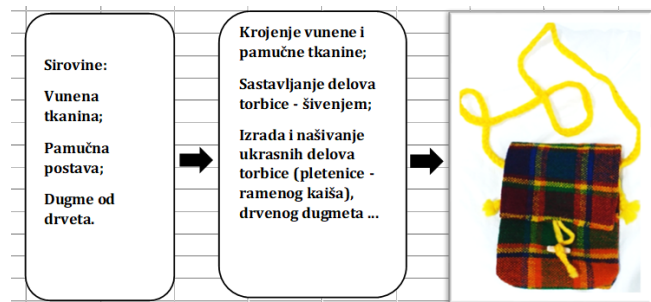


Figure 3: Technological process of ethno bag production

## 1. PRODUCT LIFE CYCLE

Life Cycle Assessment (LCA) is a standardized methodology for identifying environmental impacts by analyzing materials, energy, water, CO<sub>2</sub> emissions, and waste generated throughout all life cycle stages—from resource extraction to final disposal (ISO 14040; ISO 14044; Hauschild et al., 2018).

Sustainable development requires separating economic growth from environmental degradation by analyzing the entire life cycle of resources. Cleaner technologies promote sustainable resource use (Črnjar & Črnjar, 2009).

Production follows a circular flow, where natural resources (wool, cotton, wood) are transformed into products that satisfy human needs (Denić et al., 2021). Circular economy principles ensure that waste becomes a resource, and products are repaired, reused, or upgraded instead of discarded (Đureta et al., 2016).

Life Cycle Management (LCM) aims to minimize environmental and socio-economic burdens throughout the product life cycle (Remmen et al., 2007).

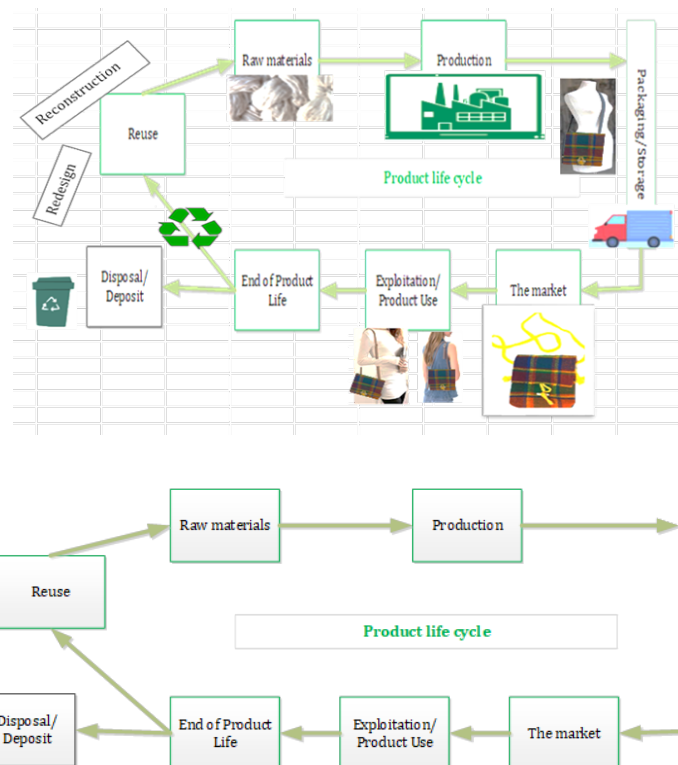


Figure 4: Schematic representation of the product life cycle – ethno bag

Transport accounts for about 20% of global primary energy consumption and significantly contributes to air pollution (Barsan et al., 2007).

The use phase reflects durability and maintenance (washing, storage, repair). Over time, wear and tear reduce functionality, making maintenance increasingly important.

The end-of-life phase is critical: the product becomes waste. Textile waste is sorted into usable and unusable categories. Usable items are resold, donated, redesigned, or reconstructed into new products such as ethno bags. Unusable waste is processed in recycling centers. Remanufacturing involves assembling products from reused and new components to achieve equal or superior quality.

## REUSE

Redesign and reconstruction extend product life. Encouraging users to repair or modify products prolongs their usability. Renting and exchanging products offer alternatives to purchasing new ones. Buying second-hand products enables access to high-quality items at lower prices while reducing environmental impact (Zrnić & Milošević, 2012).

Consumer awareness plays a key role in sustainability. Many consumers are unaware of the environmental impact of their purchases, making education essential. Informed consumers can choose sustainable products and support recycling and rental models.

Proper maintenance education helps users extend product life, reduce resource consumption, and minimize textile waste.

## CONCLUSION

The ethno bag represents a symbol of tradition, emphasizing the use of natural materials and inherited production knowledge. Woven into its structure are emotions, wisdom, and deep sentimental value tied to family heritage.

Its modern appearance, combined with colorful patterns and slight design modifications, makes it more than an artistic object. In line with sustainable development trends, it meets contemporary fashion demands.

Bags made from natural materials have a lower ecological footprint compared to synthetic ones, especially considering reuse and recycling potential. Sustainable resource management involves planning, organization, and control to achieve development goals.

The life cycle concept is a key element of the circular economy and energy transition and should be considered the foundation for addressing sustainability challenges such as climate change and resource efficiency.

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## THE IMPACT OF WEARING SYNTHETIC UNDERWEAR ON REPRODUCTIVE FUNCTIONS AND FERTILITY

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### ABSTRACT

*Textile materials made of synthetic fibers have found wide application in all spheres of human life. The textile industry is one of the the largest polluting industries oo the planet, due both to the production processes of synthetic fibers and to the accumulation of non-degradable plastic, which can only be recycled. Also, microplastics, which come from various products such as polyester clothing and the like, are found everywhere, even in water and the human body. Wearing polyester clothes has a very bad effect on human health. Chemical present in such underwear may disrupt hormonal function. Additionally, static electricity generated by these materials can interfere with the functions of the ovaries and testes. Another concern is impaired skin respiration, as syntetic fabrics do not absorb moisture. This results in damp environment in the genital area, which provides ideal conditions for the growth of microorganisms that can cause genital infections.*

**Key words:** synthetic fibers, microplastics, hormonal function, static electricity, genital infections

### 1 INTRODUCTION

Infertility in both sexes is a pressing problem in the 21st century. Infertility is becoming a more widespread health problem, so it is increasingly being searched for what leads to this problem, what can be prevented and how to cure it in men and women when it already occurs. The world and the environment in which we live is very polluted from all sides, from the air, to food, soil, etc. The textile industry is one of the biggest polluters of the planet in many ways. Synthetic fibers have long been widely used and are found all around us, not only in clothes, but also in home textiles, medical textiles, etc. Products made of synthetic fibers leave traces of microplastics all around us, and these microplastics pollute the environment, including our health, and unfortunately they are also found in human body. It comes to us through food, product packaging, clothes, etc.

The most common causes of infertility are known to medicine, and therefore the ways to treat infertility in individual cases, however, some causes are still unidentified. That's why tests and research are constantly being carried out, which should lead to progress in medicine so that the problem of infertility is less frequent, as well as curable at a high level.

Regarding textiles, they can affect the fertility of both men and women, especially in areas in direct contact with the skin and genital organs. Therefore, it is very important for people planning to conceive to pay attention to te type of underwear they wear, particularly during the preconception period.

Also, other clothes can also affect the possibility of conception, so certain research proves that very tight clothes that constrict the genital area should be avoided (Avant Gynecology, 2019).

The safest thing for both sexes is to wear underwear made of natural materials, and most often it is made of cotton. There are also underwear made of wool, bamboo fibers, etc. which can also be good for reproductive health. The problem lies in the fact that underwear is increasingly produced from synthetic fibers, polyester and polyamide, and it is mostly women's underwear. Underpants with laser-cut edges that do not show under clothes, lace lingerie and similar products are very popular on the market and sell well. Even the assortment of well-known brands of underwear are largely made from

synthetic materials (Figure 1). Therefore, the emphasis is placed on aesthetics, while functionality and the health aspect remain neglected.



*Figure 12: Synthetic women's underwear with laser-cut edges (79% polyamide, 21% elastane)*

When it was mentioned that synthetic materials have found wide application, it is important to point out that now most menstrual products for women (pads, tampons) are made of synthetic fibers (Friend of the Earth, 2018), and this information is very difficult to find on the packaging itself. This has an adverse effect on women's health, because the menstrual cycle is the most sensitive period for a woman's health, which she goes through every month and is most susceptible to infections. For example, synthetic fiber pads have the effect of creating a very moist substrate that is perfect for breeding bacteria that lead to various cervical infections. It is known that any serious infection in a woman can affect her fertility. At the same time, cotton-based menstrual products are becoming increasingly difficult to find on the market.

## **2 VARIOUS STUDIES ON THE IMPACT OF WEARING UNDERWEAR MADE FROM SYNTHETIC MATERIALS ON THE FERTILITY OF HUMANS AND FEMALE DOGS**

Several studies have been conducted on this topic, including not only humans but also animals. Some of the most well-known research was carried out on man who wore a belt made of polyester, and on female dogs that wore underwear made of different materials including polyester, in order to observe the differences in the impact of wearing various types of underwear on reproductive health and fertility. Studies have also been conducted on rats to examine the effects of wearing polyester underwear on their sexual activity etc.

### **Effects of wearing underwear made of textile materials of different composition on the fertility of female dogs**

One of the more important researches was conducted in 2008 in Cairo. Thirty-five female dogs participated in this research and were divided into five equal groups. Four groups were experimental and those female dogs wore panties of different material composition, and female dogs from the fifth group did not wear panties and they were the control group. The first group wore briefs made of 100% polyester, the second group wore a 50/50% polyester-cotton blend, the third group wore 100% cotton, and the fourth group wore 100% wool. The control group of female dogs wore no underwear at all. The female dogs wore the underpants for 12 months, and their health was monitored 6 months after they stopped wearing the underpants (Shafik, 2008).

Electrostatic potentials were not detected on the skin of any group of dogs before wearing the briefs. No potentials were detected in the groups wearing cotton or wool panties, nor in the control group. Briefs containing polyester registered electrostatic potentials, with the highest recorded for 100% polyester briefs.

In the mentioned research, it was determined that in 8 out of 14 (57.14%) female dogs dressed in panties containing polyester, a significantly low level of serum progesterone was recorded in the

estrus phase. In addition, they did not remain fertile either after mating or after insemination. The number of animals with reduced serum progesterone levels that did not become parturient was higher in the pure polyester briefs group (n = 5) than in the polyester/cotton blend group (n = 3). The cotton and wool panty group, as well as the control group, had normal serum levels of reproductive hormones during the panty-wear period and remained fertile after mating. Six months after panty removal, all female dogs had normal serum levels of reproductive hormones and remained fertile. In eight female dogs wearing polyester panties, serum progesterone levels did not increase during the estrous phase, indicating anovulation and failure to form the corpus luteum. The cause of anovulation requires further consideration (Shafik, 2008).

In these female dogs that wore underwear containing polyester, a decreased progesterone level appeared in the estrus phase. So, this is where you can see the effect of polyester underwear on fertility. Underwear made of this raw material obviously has a bad effect on the ovaries, which later leads to failed ovulation and low progesterone levels. Also, it is very important to note that lower levels of progesterone were observed in the group of female dogs that wore underwear made of 100% polyester, than in the group of female dogs that wore panties made of a mixture of cotton and polyester. The mentioned 8 female dogs could not remain fertile after mating as long as they wore this underwear (table 1.), and after stopping wearing the progesterone level increased and the female dogs managed to remain fertile. It is assumed that infertility occurs due to the bad influence of polyester that creates electrostatic potentials that arise from friction between the skin and underwear.

*Table 1: Fertility of female dogs during wearing underwear of different material composition (Shafik, 2008)*

	Pregnancy			
	Cotton	Wool	Polyester	Polyester/cotton mix
Before wearing pants	7/7	7/7	7/7	7/7
During 12 months of wearing pants	7/7	7/7	2/7*	4/7*
6 months after pants' removal	7/7	7/7	6/7**	6/7**
*The five dogs of the polyester and the three of the polyester/cotton mix group which did not conceive on mating, did not conceive either by insemination. ** The one dog in each group which did not conceive on mating was inseminated and became pregnant.				

Therefore, wearing polyester underwear causes inhibition of reproductive activities. Electrostatic potentials responsible for this inhibition were discovered on the skin of dogs. The mode of action has not yet been fully clarified, however there are indications and research is going in that direction.

The friction that occurs between the underpants containing polyester and the skin underneath generates equal and opposite charges on the inner surface of the fabric and the outer surface of the skin. A negative charge is created on the inside of the panties, and a positive one on the outer surface of the skin facing the panties. An equal but opposite charge to that on the outer surface of the skin appears on its inner side, which becomes negatively charged. Similarly, a positive charge is created on the outer surface of the fabric.

A series of induced electrostatic potentials appear to be generated, resulting in the formation of an "electrostatic field" that affects the intrapelvic structures of dogs wearing polyester briefs. Ovaries are particularly sensitive to this electrostatic field due to the germinal nature of their cells and their cyclic activity. Reduced ovarian function leads to anovulation and infertility (Shafik, 2008).

## **Bad impact of using polyester underwear on men's reproductive function**

Given the pervasive nature of endocrine disruptors, it's difficult to completely eliminate exposure. However, there are some endocrine disruptors that sneak up on us that we don't see coming - like men's polyester underwear (Šupica, 2023).

A 1992 study found that wearing a polyester girdle had detrimental effects on sperm counts in men, which served as a successful contraceptive. Over a 12-month period, a team of researchers from Cairo University School of Medicine in Egypt examined 14 male volunteers, aged between 32 and 47, who wore a polyester scrotal belt day and night. Interestingly, azoospermia developed in all participants between 120 and 160 days after initial wear (Shafik, 1992).

One intriguing finding was that none of the couples became pregnant during the study. However, all five couples who wanted to become pregnant after the study did so successfully. Of these, four couples had healthy children, and one experienced a miscarriage. It is worth noting that the testicular volume of the participants decreased significantly from 22.2 to 18.6sd ml over 12 months. However, it returned to pre-test levels 75-135 days after the belt was removed. One key aspect of the study was the examination of electrostatic potentials generated by friction between the polyester belt and the skin of the scrotum. During the day, the polyester belt generated higher electrostatic potentials (326-395 volts/sq. cm) than at night (142-188 volts/sq. cm). The azoospermic effect of the polyester girdle can be attributed to two primary mechanisms: the creation of an electrostatic field across intrascrotal structures and the disruption of normal thermoregulation (Shafik, 1992).

Research shows that wearing a polyester scrotal belt can effectively induce azoospermia in fertile men. With no significant side effects and complete reversibility of the contraceptive effect upon removal, the polyester belt appears to be a safe, acceptable, inexpensive, and unique method of contraception for men. However, further research on a larger scale is essential before this approach can be accepted as a widely accepted method of contraception (Shafik, 1992).

## **The association between underwear and reproductive health**

Fertility specialists often emphasize the importance of "keeping cool" when it comes to male reproductive health. There's a reason why the testicles are located outside the body - sperm production works optimally a few degrees below normal body temperature. Any habit that constantly heats up the groin area (whether it's frequent hot baths, putting a laptop on your lap, or yes, wearing stuffy underwear) can reduce sperm production. In fact, some urologists believe that genital heat stress is one of the key factors in male infertility that can be changed. In addition to heat, we now know that chemical exposures play a role in reproductive success in both men and women. Reducing exposure to potentially hormone-disrupting chemicals including those that may be found in clothing is increasingly being recommended as a precaution for couples trying to conceive. In short, fabric choice is a simple lifestyle change that can increase chances of success. Unlike some risk factors that are difficult to control, we can choose what you wear every day (Mr. Fertyl, n.d.).

### **3 PROHIBITION OF FULLY SYNTETIC UNDERWEAR IN CERTAIN COUNTRIES**

Some countries have recognized the harmful effect of wearing underwear made of synthetic materials on the health and fertility of men and women. As of July 1, 2024, Russia, Kazakhstan, and Belarus have banned the production, import, and sale of underwear made of synthetic materials. The law was passed because it is a fact that synthetics affect the development of bacteria in the genital area when we talk about underwear, as well as skin irritation and infertility due to the electrostatic effect on the function of the genital organs. This move led to the closure of many underwear stores, as the synthetic underwear was very popular. According to that law, underwear can be produced from textile materials containing at least 6% cotton. Therefore, the use of materials made from mixtures of natural and

synthetic materials in the production and sale of underwear is allowed, but the use of materials of 100% synthetic composition is not allowed (The World, 2014).

#### 4 CONCLUSION

Polyester, like other synthetic materials, has a very limited impact on human health, including male and female fertility. Research conducted over the years has confirmed this, suggesting that underwear made from polyester may even have contraceptive-like effect. However, further studies are needed to fully understand this phenomenon.

A major societal issue is the financial crisis, which has led people to purchase cheaper clothing and underwear. As a result, underwear made from natural materials is becoming increasingly unaffordable as economic survival takes precedence. Additionally, the general public is largely unaware of the potential negative health effects associated with wearing synthetic underwear. Awareness and information on this topic are insufficient, and many people consider wearing such underwear completely harmless.

When purchasing underwear, attention has usually focused on aesthetics, while health implications are often neglected. It is therefore essential to inform the broader population about this issue, as infertility is becoming more widespread, and awareness that even the choice of underwear may pose health risks remains low.

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## **CIRCULAR ECONOMY IN TEXTILE PRODUCTION: COMPARATIVE ANALYSIS OF THE EU AND SERBIA**

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### **ABSTRACT**

*This paper explores the implementation of circular economy (CE) principles within the textile and clothing industry, focusing on a comparative analysis between the European Union (EU) and Serbia. The circular economy aims to transform traditional linear production models based on extraction, production, consumption, and disposal into closed-loop systems that prioritize reuse, recycling, and regeneration. This paper examines the regulatory, technological, and industrial frameworks that influence circular textile production in both contexts. Emphasis is placed on eco-design, fiber recycling, resource efficiency, and the integration of Industry 4.0 tools. The findings suggest that harmonization with EU policy, combined with technological innovation and stronger collaboration between academia and industry, can accelerate Serbia's transition toward sustainable and competitive textile production.*

**Key words:** circular economy, textile industry, sustainable production, Industry 4.0, Serbia, EU integration

### **INTRODUCTION**

The textile industry is one of the world's most resource-intensive sectors, relying heavily on water, chemicals, and energy. Linear models of production, commonly summarized as take-make-dispose, lead to extensive waste generation and pollution. Globally, the transition to a circular economy is recognized as essential for sustainable industrial growth, particularly in sectors with high material intensity such as textiles.

The European Union (EU) has positioned the circular economy at the center of its sustainability agenda through the European Green Deal, aiming for climate neutrality by 2050. The Circular Economy Action Plan (2020) promotes sustainable product design, waste prevention, and recycling systems that retain material value. The textile and fashion industries are identified as priority sectors due to their environmental footprint and potential for innovation.

For Serbia, currently in the process of EU accession, adopting circular economy principles represents both a strategic and economic opportunity. It supports modernization of the textile sector, reduction of industrial waste, and creation of new green jobs. This paper provides a comprehensive comparison between EU and Serbian approaches to circularity in textile production, outlining regulatory frameworks, challenges, and examples of emerging good practices.

### **CIRCULAR ECONOMY CONCEPT IN TEXTILE PRODUCTION**

Circular economy (CE) is an industrial and economic model aimed at keeping materials and resources in use for as long as possible, thus minimizing waste (Chen X. et al., 2021). It contrasts with the linear economy that depends on continuous input of virgin resources and disposal of used products. CE emphasizes the "R-strategies", Reduce, Reuse, Recycle, and Recover, extended to 9R or 10R frameworks including Refuse, Rethink, Repair, Refurbish, Remanufacture, and Repurpose (Morseletto P., 2020).

Reduce refers to minimizing the use of resources and energy from the earliest stages of textile and garment design. This includes selecting materials with a lower ecological footprint (such as organic cotton, recycled polyester, or biodegradable fibers) and creating durable, multifunctional garments that require fewer replacements (Winans K. et al., 2017). Reuse means extending the life of textile products or components without major modification. Examples include second-hand clothing markets, garment rental platforms, and creative upcycling where fabrics and accessories are given new value through redesign (Geisendorf S., & Pietrulla, F., 2018). Recycle involves converting used textiles and production waste into new raw materials for the textile chain. This can include mechanical recycling (e.g., fiber shredding and spinning) or chemical recycling (e.g., depolymerization of polyester or nylon). While recycling reduces demand for virgin fibers, quality loss and fiber contamination remain technical challenges (Fitch-Roy, O. et al., 2020). Recover relates to the extraction of energy or valuable materials from textile waste that cannot be reused or recycled. This includes using textile residues for bioenergy production or recovering fibers and dyes through industrial processes (Morseletto, P., 2020).

Modern approaches expand these principles into 9R or 10R strategies, adapting them to textile production systems (Stoiljković B., 2023). Refuse means avoiding unnecessary products and overproduction, focusing on slow fashion and minimalism (Ab Hamid, N. et al., 2025). Rethink refers to reconsidering ownership and using models, promoting clothing rental, resale, and service-based fashion (Kyrö, R. K., 2020). Repair means to prolong garment life through maintenance and repair services (Ramírez-Escamilla, H. G. et al., 2024). Refurbish, refresh or update used garments to meet current market trends. Remanufacture or produce new clothing using recovered materials or components from returned products. Repurpose refers to finding new functions for textile waste, such as insulation, furniture filling, or composite materials (Diddi, S., & Yan, R. N. 2019).

These expanded strategies shift the focus from end-of-life solutions (recycling and waste management) toward preventive design and material circularity, ensuring that sustainability is embedded from the product's conception stage (Dissanayake, D. G. K., & Weerasinghe, D. 2022). In the textile industry, this transformation supports resource efficiency, innovation in material science, and the development of new business models aligned with the principles of sustainable fashion (Morseletto, 2020).

In the context of the textile and clothing industry, CE involves (Saha, K. et al., 2022):

- Eco-design: creating garments that are durable, repairable, and easy to disassemble.
- Material recycling: recovering fibers from post-industrial and post-consumer textile waste.
- Biobased and biodegradable materials: reducing dependence on non-renewable synthetic fibers.
- Extended producer responsibility (EPR): ensuring that producers take responsibility for the entire product lifecycle.
- Reverse logistics: collecting used textiles for reuse, repair, or recycling.

These principles are increasingly being integrated into European policies and industrial strategies, while Serbia is beginning to adapt them through pilot projects, legal reforms, and educational initiatives.

## **EUROPEAN UNION FRAMEWORK FOR CIRCULAR TEXTILE ECONOMY**

The EU has developed an extensive policy and legal framework that sets measurable targets for waste prevention, recycling, and product design. Main elements include:

- Waste Framework Directive (2008/98/EC; amended 2018/851): establishes the waste hierarchy and EPR obligations for producers (Waste Framework Directive, 2023).

- Packaging and Packaging Waste Directive (94/62/EC): defines recycling targets for different packaging materials (Packaging Waste, 2024).
- Circular Economy Action Plan (2020): identifies textiles as a priority sector for innovation, recycling, and consumer awareness (A new Circular Economy Action Plan, 2020).
- European Green Deal (2019): aims to achieve climate neutrality by 2050, promoting sustainable resource use and zero pollution (European Green Deal, 2019).

The EU's approach demonstrates that the transition toward a circular textile economy requires coordinated action across all levels of the value chain such as manufacturers, designers, retailers, and consumers. Emphasis is placed not only on waste reduction but also on the creation of new business models that extend product life cycles and increase material efficiency (Köhler, A. et al., 2021). By integrating environmental and economic goals, the EU provides a model of systemic transformation in which circularity becomes a driver of innovation and competitiveness (Bour, A., 2023).

This framework serves as a useful point of reference for other countries in the process of aligning their policies and practices with European standards, particularly those aiming to modernize their industries and strengthen their participation in sustainable global value chains (Fischer, A., & Pascucci, S., 2017).

## **SERBIAN FRAMEWORK AND CURRENT DEVELOPMENTS**

The circular economy in Serbia is still in the early stages of development, but in recent years there has been significant progress through the creation of strategic documents, legislative amendments, and institutional initiatives (Vukelić I., 2023). Serbia is the first country in the Western Balkans to develop the “Circular Economy Roadmap”, a strategic document that defines the transition toward a sustainable economic model focused on resource preservation and environmental protection (Mashovic A., 2022). Amendments to the Law on Waste Management in 2016 introduced the terms “by-product” and “end-of-waste status,” aligning national legislation with EU regulations (Pavlović M., 2020).

Despite progress, implementation challenges persist. These include limited waste management infrastructure, insufficient coordination between governmental bodies, lack of public awareness, and restricted financial incentives for green investments (Marinković T., 2023). Educational programs and public-private partnerships remain underdeveloped, which slows down practical application in the textile industry (Vasić B., 2023). However, several pilot projects and startups have emerged that focus on textile waste recycling, fiber recovery, and sustainable fashion design. Universities and research centers are increasingly including CE concepts in curricula, fostering collaboration between academia and industry (Mahalingam, T., 2024).

## **DISCUSSION: INDUSTRY 4.0 INTEGRATION**

The transition toward a circular textile economy requires not only regulatory alignment and environmental awareness but also a technological foundation capable of supporting complex, data-driven production systems. In this context, Industry 4.0, the digital transformation of manufacturing through automation, connectivity, and intelligent systems represents a main enablers of circularity (Ali, S. et al., 2024). The textile and clothing industry, characterized by long supply chains and high resource intensity, can particularly benefit from digital integration. Advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), robotics, and blockchain allow for continuous monitoring, optimization, and transparency across all stages of the product lifecycle. By linking production data with environmental performance indicators, companies can make informed decisions about material use, energy efficiency, and waste management (Ghoreishi M. et al., 2020).

In circular textile systems, digitalization supports traceability of fibers and materials, enabling producers and consumers to track origin, composition, and environmental impact. Smart manufacturing solutions contribute to greater flexibility and customization, reducing overproduction and unsold inventory. Furthermore, predictive analytics can forecast maintenance needs or recycling potential, ensuring that textile products remain in circulation for as long as possible (Nascimento D. L. M. et al., 2019). On a broader level, blockchain-based traceability systems can ensure data integrity throughout the supply chain, building consumer trust in sustainability claims and enabling the verification of recycled or ethically sourced materials. Combined with circular business models such as product-as-a-service, clothing rental, or repair and refurbishment platforms, these technologies form the infrastructure of a new, transparent, and sustainable textile economy (Dal Forno, A. J. et al., 2023).

For Serbia, the integration of Industry 4.0 tools into textile manufacturing is not merely a question of modernization but a strategic necessity for aligning with European standards and improving competitiveness. Digital transformation can help domestic companies meet circular economy requirements, reduce resource consumption, and strengthen their position in international markets. Collaboration between universities, technology providers, and textile producers is essential to build the technical and managerial capacities needed for this shift (Lalic, B. et al., 2019). In this way, Industry 4.0 acts as both a technological and organizational bridge between traditional manufacturing and the circular economy enabling Serbia's textile sector to evolve toward innovation-driven sustainability, greater efficiency, and long-term economic resilience (Bojić, M. M. S. et al., 2024).

## **CONCLUSION**

Circular economy offers a comprehensive framework for sustainable and competitive textile production. The EU has already established an advanced legislative and strategic foundation, while Serbia is in the process of adaptation and gradual implementation. The comparative analysis indicates that policy alignment, institutional strengthening, and technological modernization are key to accelerating progress.

Integrating Industry 4.0 tools into textile manufacturing can significantly improve resource efficiency and transparency. To ensure long-term success, Serbia must enhance cross-sector collaboration, promote eco-design standards, and develop incentive mechanisms for recycling and reuse. By leveraging EU programs such as Horizon Europe and the Green Deal, Serbia's textile industry can achieve a sustainable transition and contribute to regional green growth.

The circular economy represents a fundamental shift in how production systems are organized and how value is generated across the textile and clothing sector. Rather than focusing only on waste management and end-of-life processes, it establishes a comprehensive model that integrates sustainability at every stage, from material sourcing and design to manufacturing, distribution, and consumption. In this context, the textile industry has a unique opportunity to become a driver of industrial modernization, technological advancement, and sustainable economic growth.

For the European Union, the circular economy has evolved from an environmental initiative into a structured economic policy framework that connects industrial competitiveness with social and ecological responsibility. The combination of legislative measures, financial instruments, and innovation programs has enabled a clear strategic direction and measurable results. These instruments ensure that sustainability is not a constraint, but a productive factor embedded into the European industrial model.

In Serbia, the transition to a circular textile economy is still in an early stage. The legal and strategic frameworks have introduced important concepts, but their implementation remains limited. The main

obstacles include insufficient infrastructure for textile waste collection and recycling, weak enforcement of environmental legislation, lack of incentives for industry transformation, and low public awareness. Additionally, small and medium-sized enterprises, which make up the core of Serbia's textile sector, often lack the financial and technological capacity to adopt circular business models.

Addressing these challenges requires a coordinated approach that links national policies with European integration processes. Strengthening institutional capacity, developing fiscal and financial instruments for green investments, and establishing platforms for cooperation between research institutions and industry are essential. Education also plays a crucial role, incorporating circular economy principles into engineering, design, and management curricula can ensure that future professionals possess the skills needed to implement circular models in practice.

The integration of Industry 4.0 technologies such as digital monitoring, automation, data analytics, and traceability systems can accelerate this transformation by enabling efficient resource management, transparent supply chains, and informed decision-making. When combined with eco-design and extended producer responsibility, these tools can close material loops and reduce dependence on imported raw materials, contributing to Serbia's economic resilience. The goal is not only to align Serbia's textile industry with EU standards but to build a competitive, knowledge-based sector capable of generating innovation and employment while minimizing environmental impact. The transition toward a circular textile economy should therefore be viewed as an investment in long-term stability and industrial modernization, rather than as a regulatory obligation. With consistent implementation, and access to EU funding mechanisms, Serbia's textile sector can evolve from a resource-intensive industry into a model of sustainable production for the wider region.

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**STUDENT PAPERS**

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## THE PSYCHOLOGY OF COLOR IN FASHION

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### ABSTRACT:

Colors play a significant role in our daily lives, extending far beyond visual aesthetics to influence emotions, identity, and self-expression. In contemporary society, colors are widely used in various professions, including fashion, where they serve as a powerful tool for enhancing personal appearance and conveying messages about the wearer. The study of colors in fashion, often referred to as "Color Analysis," has gained increasing attention, with experts in many countries providing professional guidance on the subject. This paper explores the psychology of color in fashion, focusing on how colors reflect emotions, shape identity, and communicate information about individuals. By examining specific analyses and experiments, the research aims to identify which colors best complement different people and how these colors can be used effectively to enhance their image. Understanding the psychological impact of color allows both designers and consumers to make informed choices, creating a more intentional and expressive approach to fashion. Ultimately, this study demonstrates that color is not merely a decorative element but a dynamic medium through which people express personality, mood, and social perception, highlighting its importance in the fashion industry.

**Keywords:** color psychology, fashion, color analysis, self-expression, identity, emotions, visual aesthetics, personal image.

### 1. INTRODUCTION

Colorpression, reflecting emotions, personal identity, and social perception. The concept of "Color Analysis" has gained increasing attention, with professionals guiding individual aspect of human perception and plays a significant role in various spheres of life, including fashion. In contemporary society, color is widely used by both men and women to enhance their visual appeal and express individuality. Beyond aesthetics, colors serve as a means of self-ex tures. This study explores the psychological impact of color in fashion, examining how colors influence emotions, identity, and personal style, and how they communicate information about the wearer.

### 2. THE PSYCHOLOGICAL EFFECTS OF COLOR IN FASHION

Colors evoke specific emotional responses and contribute to the perception of brands and individuals. For example:



Figure 1: colors in fashion

**Red** symbolizes passion, energy, and confidence, often associated with bold statements (e.g., Valentino). **Blue** conveys calmness, stability, and trustworthiness (e.g., Tiffany & Co.). **Black** denotes elegance, sophistication, and authority, frequently used in luxury fashion (e.g., Chanel, Yves Saint Laurent). **White** represents purity and minimalism, commonly applied in bridal and minimalist fashion (e.g., Calvin Klein, Dior). **Yellow** evokes optimism, creativity, and energy (e.g., Versace, Fendi). **Green** reflects nature, harmony, and sustainability (e.g., Stella McCartney, Vivienne Westwood). **Purple** is associated with luxury, creativity, and spirituality (e.g., Alexander McQueen, Versace).

### 3. COLORS AND PERSONAL STYLE

Fashion is a form of art used to express personality and individual taste. Different styles incorporate colors differently:



Figure 2: personal style

**Casual:** Comfortable, relaxed, everyday wear.

**Minimalist:** Focused on essential pieces with moderate color use.

**Chic:** Elegance through refined and subtle details.

**Formal:** Structured, professional outfits for special occasions.

**Bohemian:** Freedom in combining garments with vibrant and eclectic color choices.

**Vintage:** Nostalgia and retro elegance using classic color palettes.

#### 4. COLOR IN FASHION TRENDS

Color is central in shaping fashion trends. Primary (red, blue, yellow), secondary (green, orange, purple), and tertiary colors are combined to create visual impact. Color, in harmony with material, shape, and texture, determines the perception and success of fashion products. Fashion trends and color choices are influenced by societal shifts, with institutions like Pantone Designating the Color of the Year, guiding designers in their seasonal collections.

#### 5. CULTURAL AND SOCIAL INFLUENCES

Traditional clothing reflects cultural heritage and identity through colors, patterns, and craftsmanship. Examples include:

**Sari** (India), **Kimono** (Japan), **Hanbok** (Korea), and **Serbian folk costumes**, each representing social status, tradition, and aesthetics. Understanding cultural significance enriches fashion choices and promotes global appreciation of diversity.

#### 6. CHOOSING COLORS ACCORDING TO SKIN TONE

Selecting colors based on skin undertones enhances natural beauty and visual harmony. Skin undertones are classified as:

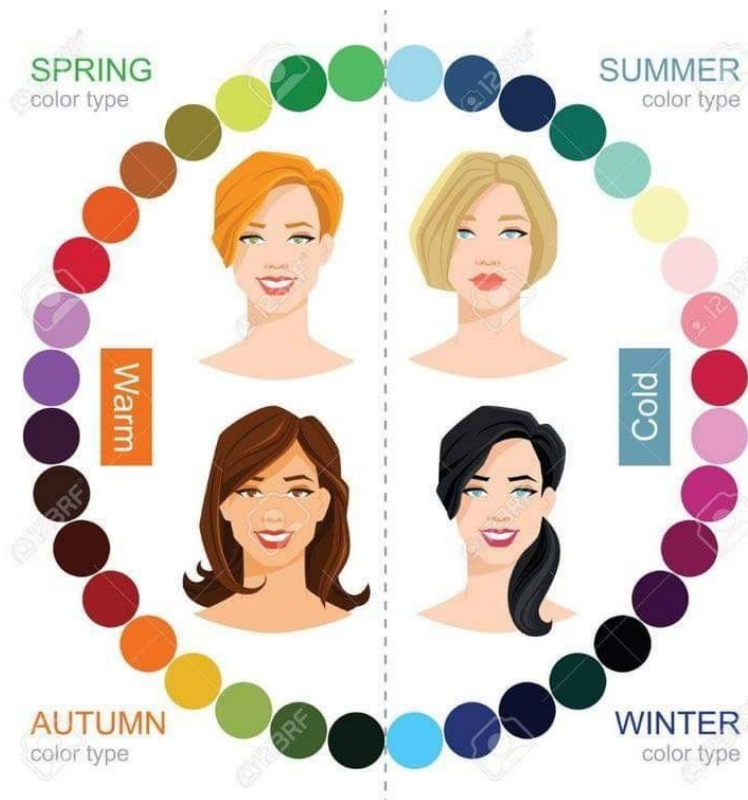


Figure 3: colors for all skin type

**Warm:** Golden or yellowish hues; best complemented by earthy tones.

**Cool:** Pink or bluish hues; best complemented by jewel tones and silver.

**Neutral:** Balanced undertones; compatible with both warm and cool colors. Methods for determining undertones include vein observation, jewelry tests, and sun exposure response. Choosing colors aligned with undertones enhances confidence and appearance.

## 7. COLOR ANALYSIS

Color Analysis helps identify which colors best suit an individual based on facial features, hair, and skin. Modern approaches categorize colors into twelve seasonal palettes, building on the traditional four-season model (Spring, Summer, Autumn, Winter) by incorporating three dimensions of color:

1. **Temperature:** Warm vs. cool tones.
2. **Value:** Lightness or darkness.
3. **Chroma:** Intensity or saturation.

This refined approach allows nuanced matching of colors to natural features, acknowledging that individuals may fall between multiple categories. Properly selected colors enhance the complexion, highlight natural features, and support aesthetic and psychological well-being.

## 8. CONCLUSION

The psychology of color in fashion significantly affects perception, emotions, and behavior. Beyond aesthetics, color has cultural, social, and psychological implications, influencing mood, confidence, and self-expression. Understanding color psychology enables designers and consumers to make informed choices, creating meaningful visual identities and enhancing individual style. Through strategic use of color, fashion becomes a medium of personal expression and social communication.

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## **SYNTHETIC FIBERS AS A SOURCE OF MICROPLASTICS: AN ECOLOGICAL ANALYSIS OF THE TEXTILE INDUSTRY**

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### **Abstract :**

*The textile industry in modern production largely relies on the use of synthetic fibers. Chemically produced fibers such as polyester, acrylic, and nylon are widespread due to their availability, as well as their low cost and rapid production compared to natural fibers. Synthetic fibers bring numerous benefits in the production of textile materials, but at the same time they represent one of the leading sources of microplastic pollution, which results in a major ecological problem. This paper examines the ecological consequences of using synthetic fibers with a focus on the formation and distribution of microplastics, as well as their impact on ecosystems and human health. The paper also emphasizes the importance of consumer education about sustainable production and the development of circular fashion. Furthermore, research shows that during each wash of a single synthetic garment in a washing machine, thousands of tiny microplastic particles are released, passing through filters and reaching rivers and seas. These particles are highly persistent and difficult to decompose, and over time they accumulate in marine organisms and eventually in the human body through food consumption. The issue of microplastics is becoming a global challenge because it affects not only biodiversity but also the quality of human life. Solutions include the development of new filtration technologies, encouraging the production of biodegradable materials, and increasing the responsibility of fashion brands. Only through a combination of innovation, proper regulation, and consumer awareness is it possible to reduce the negative effects of synthetic fibers on the environment.*

**Key words:** synthetic fibers, microplastics, textile industry, ecological impact, sustainable consumption

### **1. INTRODUCTION**

The term microplastics emerged at the beginning of the 21st century as a concept referring to microparticles with sizes ranging from 50 micrometers to 5 millimeters. These particles are made of carbon-based polymers. [1,2,3] Today, microplastics represent a major ecological problem due to the increasing improper disposal of waste and excessive use of synthetic materials in clothing production. This leads to the accumulation of microplastic particles in water and soil, and they often end up in the bodies of animals and humans. [4] Although the textile industry is not the only source of environmental pollution, it represents one of the significant sources of microplastics, primarily because of the intensive use of synthetic fibers, which are easily released into the environment during washing and everyday use. The most common source of microplastics from textiles comes from clothing made entirely of synthetic materials or containing a certain percentage of synthetic fibers, most often polyester. During the washing of polyester garments, a large amount of microplastic particles is released during the first washes. With frequent use, wear and tear of the clothing occurs, which further releases fibers through tearing. Today, the use of synthetic fibers in the industry is increasing, which in turn amplifies the harmful impact of the textile industry on the environment. [5,6] The question arises as to how the negative impact caused by microplastics can be reduced, particularly through the improvement of production processes, the use of more environmentally friendly materials, the adoption of ecological practices in washing and maintenance, and the recycling of clothing.

### **2. SYNTHETIC FIBERS: ORIGIN, PROPERTIES, AND ROLE IN TEXTILES**

#### **2.1. Historical Development and Application of Synthetic Materials in the Textile Industry**

The first synthetic fibers appeared at the beginning of the twentieth century as a response to market demands. Cellulose, as a natural polymer, was the most common, followed by viscose, which accounted for the majority of fiber production obtained through synthetic processes. Nylon, acrylic, and polyester are considered the first official synthetic fibers, with their development driven by industrial centers in Germany, Italy, and the United

States. Today, artificial fibers are the most widely used in the global textile industry, and there is increasing discussion about the sustainability of synthetic materials and environmental protection. [6] In the 1930s, with the use of petroleum derivatives, nylon was introduced, and only afterward did the chemical-textile industry begin developing other synthetic fibers. These fibers are obtained chemically through the synthesis of petroleum derivatives and can be produced in unlimited quantities, making them ideal for textile production. When combined with natural fibers such as cotton or wool, the textile industry attempts to establish a balance, but such clothing often has a short lifespan and, after only a few uses and washes, ends up in landfills. [8] The production of synthetic fibers began as a solution to the problem of mass production. Synthetic fibers have unlimited length and are not affected by climatic changes, unlike natural fibers, making them suitable for clothing, home textiles, and technical textiles in the fashion and apparel industry. [10] The most common type of synthetic fiber is polyester, which is also the most widely used. Polyester fiber is obtained from a linear type of polymer resulting from the polycondensation of a diol and a dicarboxylic acid. The fiber exhibits exceptional durability under friction, maximum tensile strength, and the ability to return to its original state after deformation. [9] In addition to polyester, nylon and acrylic fibers are equally used in textile production. Acetate fiber, derived from natural polymers, is comparable to polyester in terms of prevalence. Its origin comes from diacetyl cellulose and triacetate, indicating that there are two types: diacetate and triacetate. Acetate fibers are used in the production of lingerie, nightwear, everyday clothing, and often children's clothing. [9]

## **2.2. Determinants of the Prevalence of Synthetic Fibers in the Textile Industry and Their Negative Impact on the Ecosystem**

Since their inception, synthetic fibers have been widely used due to their low cost and rapid production, as well as their independence from climatic changes and geographic location. Unlike natural fibers, synthetic fibers are produced independently of traditional stages of cultivation and raw material processing. They are obtained through polymerization, forming long molecular chains, which makes them suitable for meeting market demands and the fast fashion effect, which today has a significant influence on consumers. Synthetic fibers are most often used in blends with cotton and other natural fibers, but even in combination with other fibers, their production is significantly more economical. The production of synthetic fibers positively contributes to the circular economy, as they can be manufactured in unlimited quantities, saving labor, time, and reducing the use of natural resources, thus allowing better allocation of financial resources, giving them an advantage over natural fibers. [11-14] Although synthetic fibers are dominant, their negative impact on the ecosystem is increasing. The production of these fibers contributes to the greenhouse effect through harmful gases, and during the washing of garments made from these fibers, a certain amount of microplastics is released, threatening ecosystems and the health of living beings. The textile industry significantly affects the environment, as an average of 79 trillion liters of water is consumed annually in the production of textile materials, while emissions of harmful gases released into the atmosphere account for approximately 8–10%, with some variation. During polyester washing, 16–35% of microplastic particles are released into the water, which can severely threaten aquatic life. Additionally, textile materials require a long time to decompose, and a large portion of materials that end up in landfills is not recycled, further contributing to environmental degradation. [15] Modern textile industry relies heavily on synthetic materials because they are more economical and can be produced in large quantities. Synthetic materials such as nylon, polyester, and others are used in mass production and ensure reliable profit. Although they allow the production of diverse textile products, their manufacture is based on fossil raw materials, which release harmful gases into the atmosphere. The spread of microplastics extends pollution to aquatic ecosystems and contributes to climate change, leaving a significant ecological footprint.

## **4. MICROPLASTICS IN THE TEXTILE CONTEXT**

### **3.1. Definition and Classification of Microplastics**

Microplastics are small particles ranging in size from 1  $\mu\text{m}$  to 5  $\mu\text{m}$ . These synthetic particles are insoluble in water, leading to severe ecosystem pollution and increasing harmful effects on the health of humans and marine animals. Microplastic particles are divided into primary and secondary types. Secondary microplastics are generated during the washing of synthetic materials, through the wear of rubber, or from the degradation of plastic films, while primary microplastics are intentionally produced for use in industries such as textiles or cosmetics. [16] One of the most common sources of microplastics in everyday life comes from clothing and textile products made of polyester and nylon. Microplastic particles are released from garments during washing

as well as through regular wear. These particles are not intentionally produced and belong to the category of secondary microplastics. In addition to textile materials and products, other sources of secondary microplastics include toys, bottles, and plastic bags, which can become highly harmful under the influence of sunlight, waves, and other external factors. [17] Plastic that ends up in the environment cannot decompose quickly and often requires centuries to fully break down. The presence of microplastics can be detected in aquatic ecosystems, as well as in drinking water and food. [18] Research has shown that microplastics have entered the bodies of plankton and other marine animals. [18] This type of ecological problem represents a hidden threat to nature and the future of living organisms for upcoming generations.

### **3.2. Release of Microfibers from Textiles during Wearing and Washing: Mechanisms and Influencing Factors**

Microfibers represent a major problem in aquatic ecosystems, and one of the most significant sources of pollution is the washing of clothes at home. Processed polyester is the main cause of microfiber release during washing, but fibers such as wool and cotton also release micro-particles during production and washing, although in smaller quantities compared to polyester. [19] Research has shown that washing machines contain as many microfibers as the oceans, regardless of whether synthetic clothing or garments made from natural materials, such as wool or cotton, are being washed. Even during the washing of natural fibers, microfibers detach from the material. To prevent this, it is recommended to install washing machine filters that can prevent up to 90% of microfiber release into the environment. [20] During the rotation of the washing machine drum, mechanical wear and chemical effects occur. [20] The use of powdered detergent, laundry capsules, and fabric softeners in combination with warm water leads to the release of microplastic particles, which then enter the environment through sewage systems. Water temperature does not significantly affect the release of microplastic particles; the most important factors are the volume of water used and the frequency of washing. The highest number of fibers is released during the first five washes, after which the number of released particles decreases slightly. To prevent excessive fiber loss, attention must be paid during the production of garments, regardless of the material used. Focus should be on the technological process of production, finishing of the fabric, and quality control to minimize the amount of microfibers detached from the textile. [21]

### **3.3. Infrastructural Issue: Lack of Filtration Systems in Wastewater**

One of the most significant factors contributing to microplastic pollution is the efficiency of wastewater treatment systems. The current systems in use can remove some particles but are not fully effective. [27] Compared to the European Union, Serbia treats only 15–20% of its wastewater, which is significantly lower than in the EU. One-third of treatment plants are non-functional due to outdated technology and underdeveloped infrastructure. Coordination is also poor, and there is a noticeable shortage of trained personnel. From the perspective of circular economy interests, this situation can be seen as advantageous, as economic benefits arise from viewing sludge and water as resources that generate profit. [28] This demonstrates that environmental awareness is not at a satisfactory level, and economic profit is often considered more important than the health of living organisms. Such a mindset extends to consumers and future generations, contributing to increasing pollution, even as discussions on sustainability and environmental protection become more prominent today.

## **4. ECOLOGICAL CONSEQUENCES OF MICROPLASTIC IMPACT**

A significant portion of microplastics originates from textile materials. During washing, drying, and regular use of clothing, tiny plastic particles enter the environment through water treatment facilities. They are most commonly found in aquatic ecosystems, including rivers, seas, and lakes, and can even reach drinking water through pipelines. Small plastic particles have been detected in the bodies of fish, plankton, and even humans, significantly affecting the health of all living organisms and the food chain. The small size of microplastics allows them to easily penetrate tissues and move through the food chain. Even if an animal or human has not come into direct contact with microplastics (which is highly unlikely), there is a high probability of ingesting meat from animals that have already accumulated microplastic particles. This leads to the transfer of chemicals and microorganisms, potentially causing serious health consequences. [24] Microplastics can significantly impact fertility in both women and men. Tiny microplastic particles can enter the follicular fluid of female ovaries, which may considerably reduce reproductive capacity, as they contain chemicals such as PFAS, phthalates, or bisphenol, which can cause hormonal disorders and damage reproductive cells. [25] It has been proven that microplastics have been found in blood, breast milk, arteries, and human placentas during

pregnancy, negatively affecting fetal growth and development, as well as the health and behavior of the child throughout life. [26] Through plastic bottles, single-use cups, careless disposal of plastic bags, and textile materials—especially products whose lifespan has ended without proper recycling—the oceans and water systems have effectively become living landfills, systematically harming aquatic life and long-term biodiversity, disrupting ecosystem balance. This represents a major ecological problem with serious consequences for future generations. If the use of plastics and synthetic materials is not reduced, there is a risk of declining fertility globally, as well as negative impacts on the development of living organisms, potentially creating emotional, health, and economic consequences.

## **5. HEALTH AND SOCIAL ASPECTS OF THE PROBLEM**

Microplastics have an extremely harmful impact on health. Humans ingest microplastics through food and beverages, as well as through the respiratory system. Nano-sized particles pose a significant risk because they can reach the respiratory parenchymal organs, the cardiovascular system, the liver (Hepar), and even the brain (Cerebrum). Due to their extremely small size, they can penetrate physiological barriers and cause serious health problems, such as immune system disorders, tissue damage, and reduced fertility. Microplastics can accumulate in the body without our awareness, posing a significant risk to the gastrointestinal and alveolar barriers, among others. Animals are even more exposed to the risks of microplastics. Marine and aquatic animals, as well as birds, often ingest microplastics while searching for food. Plastic in their stomachs creates a false sense of satiety, leading to reduced food intake, weight loss, and eventually death. The presence of chemicals, metals, and various additives causes poisoning, leading to lethargy. [32] Additionally, textile materials, whether made from natural or synthetic fibers, contain microplastics due to the fibers themselves and the dyes used. [28] Microplastic particles circulate through water and air, and their breakdown contributes to soil degradation. The world and Europe have recognized the significance of microplastics, but despite this, people continue to use them, as environmental awareness is still insufficiently widespread, as is awareness of the negative effects of microplastics. [29] The question arises: who is responsible? The greatest responsibility lies with industries such as the textile and cosmetic industries. However, a portion of the impact comes from society itself, which is not ecologically responsible. Additionally, fast fashion as a global trend imposes constant changes in clothing. To meet market demands, the textile and fashion industries must produce synthetic materials with unlimited length, regardless of their harmful effects on living organisms.

## **6. POSSIBLE SOLUTIONS**

The negative impact of microfibers is inevitable, but to reduce it, consumer education about the harmful effects of both synthetic materials and plastics is essential. Consumer behavior must change; it is not enough to simply use eco-friendly bags when shopping. Awareness of the importance of environmental protection must be raised on a global scale. In the textile industry, the use of synthetic materials such as polyester, nylon, acrylic, and others, as well as the fast fashion trend, must be significantly reduced. Synthetic materials should be replaced with natural fibers, although they also release microplastics to some extent. Attention should be paid to the care and use of clothing. Washing machines equipped with built-in purification filters are recommended, as they can reduce microfiber emissions by up to 80%. It is advisable to use mild fabric softeners, avoid washing clothes at high temperatures, and minimize the use of powdered detergents. Recycling and circular fashion could reduce the presence of microfibers. Clothing should be repaired or redesigned, reducing the need for new garments, which would extend the lifespan of clothes and encourage reuse after a few wears. Efforts should also focus on waste treatment and the implementation of efficient wastewater purification systems to remove a larger portion of microfibers from pipes. Sludge control is necessary, as it is often used as soil fertilizer, which would significantly reduce the presence of microplastics in aquatic ecosystems and soil. [31]

## **7. CONCLUSION**

Microplastics represent a major ecological problem for the entire planet. Their negative impact affects all aspects of living organisms. The greatest effects are seen in humans and animals, whose health is significantly endangered, often with lasting consequences. Reduced immunity, decreased fertility, developmental issues, and even death are among the consequences of this serious problem. Microplastic particles are almost invisible, but this does not diminish their harmful effects on biodiversity. The largest source of microfiber pollution is the textile industry through the production of synthetic fibers, although the cosmetic and plastic industries also contribute significantly. Wastewater treatment systems cannot completely remove microplastic particles, which

further exacerbates the problem. Micro-particles circulate in the environment through water, air, and soil. They enter organisms through food and drink, penetrating physiological barriers. Animals may ingest plastics, mistaking them for food, creating a false sense of satiety. To reduce the negative impact of microplastics, awareness of their harmfulness must be raised, and the influence of fast fashion and synthetic material production must be reduced. Microplastics are a silent but persistent enemy. To save our planet, joint efforts from manufacturers, consumers, industries, and environmental responsibility are essential to raise awareness about the importance of environmental protection and the harmful effects of microplastics, which would greatly aid the fight against pollution. We must make conscious decisions regarding clothing purchases, production methods, and waste disposal. If necessary measures are not taken, future generations will be put at risk. Let the legacy we leave to future generations be health and nature, not plastic. Let us choose health, a cleaner and more beautiful environment, and a responsible approach to the future. This issue concerns all of us.

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## CHEMICAL TESTING OF TEXTILE MATERIALS AND METHODS OF FIBER IDENTIFICATION

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### ABSTRACT

*This paper investigates the chemical testing and analytical evaluation of major textile fiber classes (cellulosic, protein and synthetic origin). The research explores chemical reactivity of these fibers toward acids, alkalis and various organic and inorganic reagents, elucidating the influence of fiber chemical composition and morphology on their degradation and performance characteristics. Standard identification techniques - including burning behavior, dry distillation, solubility in mineral and organic solvents, differential dyeing and microscopic examination - are systematically applied to differentiate fiber types and assess their composition.*

**Key words:** textile fibers, chemical characterization, fiber identification

### 1. INTRODUCTION

Chemical testing of textile materials reveals harmful substances, ensuring that the textiles do not contain irritants or allergens that could cause adverse effects upon direct contact with the skin. In this way, compliance with specific regulations and quality standards established by renowned textile manufacturers is confirmed. These standards cover aspects such as safety (in use) by detecting and quantifying harmful substances, environmental protection through alignment with sustainability practices and regulations, proper labeling and the assessment of textile performance and durability - including colorfastness, strength and resistance to various factors. [1]

### 2. CHEMICAL TESTING OF TEXTILE MATERIALS

#### 2.1. *The Influence of Chemical Agents on Textile Materials of Different Origins*

**Textile fibers** are thin, flexible filaments whose length is many times greater than their cross-sectional dimension. Their basic classification is according to origin - natural fibers (which include plant-based→ cellulosic, animal-based→protein, and mineral fibers) and chemical fibers, which are produced from natural or synthetic polymers and inorganic substances. [2]

##### 2.1.1. *The Influence of Acids on Textile Materials of Cellulosic Origin*

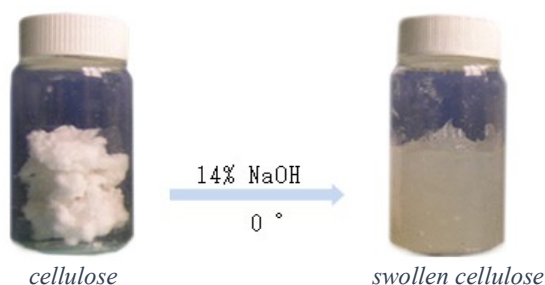
**Cellulose** is a stereoregular polymer composed of linear macromolecules of poly-β(1-4)-D-anhydroglucopyranose, with cellobiose as the repeating unit. Cellulosic fibers exhibit instability when exposed to aqueous solutions of acids and acid salts, which cause the hydrolysis of the glycosidic bond. [3][4]

When each glycosidic bond is broken, two macromolecules are formed, and the reducing ability of cellulose doubles, since each molecular chain ends with a hemiacetal group that easily converts into an aldehyde group - i.e., into a reducing form. The resulting aldehyde group can reduce Cu<sup>2+</sup> ions to Cu<sup>+</sup> (forming Cu<sub>2</sub>O → a reddish-brown precipitate) from Fehling's solution (an alkaline solution of copper(II)oxide, CuO). This reaction is used to quantitatively determine the degree of cellulose degradation. The result is expressed as the so-called copper number, which represents the number of milligrams of copper reduced by 100 g of dry cellulose. The amount of reduced copper indicates the degree of cellulose degradation caused by the formation of aldehyde groups. The product is called *hydrocellulose*, which shows increased reducing ability and increased solubility in alkaline solutions,

as well as decreased viscosity of its cuprammonium solutions and reduced tensile strength. When severely damaged by acids, the fibers become brittle and after drying, easily turn into powder. This behavior of hydrocellulose is utilized in the carbonization process of wool and woollen products, which serves to remove plant impurities and burrs. [4]

### **2.1.2. The Influence of Alkalis on Cellulosic Fibers**

Dilute solutions of sodium hydroxide at room temperature do not cause damage to cellulose. When concentrated alkaline solutions are used, a new compound - alkali cellulose is formed, containing 0,5-2 moles of alkali per mole of cellulose (Figure 1). [4]



*Figure 13: Effect of NaOH on cellulosic fibers*

The treatment of cellulose with alkalis is known as *mercerization*. Mercerization is a chemical process for enhancing cotton, in which the fibers are treated with 18-25% sodium hydroxide in a cold medium or, more commonly, at temperatures above 60 °C. After a treatment lasting 50-120 seconds, the fibers, in their stretched state, are rinsed with hot, soft water and then washed. The final product is fibers with increased luster, strength, improved absorbency and a better hand feel. [4][5]

### **2.1.3. The Influence of Oxidizing Agents on Cellulosic Fibers**

When cellulose is exposed to oxidizing agents, it undergoes oxidation, which is a topochemical reaction, resulting in the formation of *oxycellulose* - a heterogeneous, complex mixture of macromolecules oxidized to varying degrees. Hydrocellulose and oxycellulose differ in the presence of carboxyl groups. Compared to undamaged cellulose, oxycellulose has lower strength, reduced solution viscosity and increased reducing ability and solubility in alkaline solutions. The process of oxidative degradation of cellulose concludes with the cleavage of glycosidic bonds and depolymerization of the macromolecules. [4]

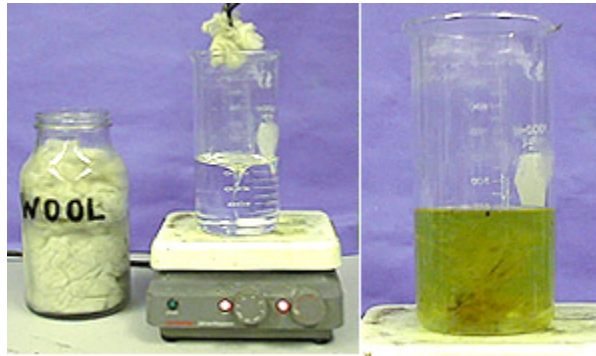
## **2.2. The Influence of Chemical Agents on Protein Fibers**

**Wool** is a heterogeneous assembly of proteins with different structures. Keratin molecules are helically coiled and contain numerous reactive atomic groups: the polar peptide group  $-C(=O)NH-$ , as well as carboxyl, hydroxyl, and amino groups. [2][3][6]

### **2.2.1. The Influence of Acids, Alkalis, Oxidizing and Reducing Agents on Wool Fibers**

Protein fibers, primarily wool, silk, and other animal hairs, are relatively resistant to the action of mineral acids, even at elevated temperatures. Boiling concentrated sulfuric acid completely decomposes wool fibers, while nitric acid causes oxidation of wool, accompanied by damage and the appearance of an orange-brown coloration → the *xanthoproteic reaction*. [7]

The degree of damage to protein fibers by alkalis depends on their concentration, type and the temperature at which the treatment is carried out. Under the influence of 5% NaOH at room temperature, wool fibers lose strength and elasticity, while boiling 5% NaOH rapidly dissolves wool (Figure 2). Strong alkalis initially hydrolyze polypeptide chains, break hydrogen bonds and hydrolyze disulfide bonds. [8]



*Figure 14: Destruction of Wool Fibers under the Action of Concentrated NaOH*

Exposure to oxidizing agents leads to the breakdown of disulfide bonds within wool fibers, resulting in a decrease in total sulfur content and an increase in free sulfur content. Consequently, the solubility of wool fibers in alkaline solutions increases. Reducing agents, such as SO<sub>2</sub>, have a minimal effect on wool and can be used for bleaching. However, hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) is more suitable than SO<sub>2</sub> for the bleaching process, as the whiteness achieved with sulfur dioxide is not stable. Therefore, a so-called combined oxidative-reductive bleaching is used. [8]

### **2.3. The Influence of Chemical Agents on Synthetic Fibers**

Unlike natural fibers, which exist in that form in materials from nature, chemical fibers are produced either from natural fibrous substances through physico-chemical processing (chemical fibers from natural polymers) or from substances obtained through chemical reactions (chemical fibers from synthetic polymers and inorganic materials). [2][3]

**Polyamide fibers (PA)** are resistant to dilute acids and alkalis, but unstable when exposed to concentrated acids and oxidizing agents. **Polyester fibers (PES)** are resistant to acids, oxidizing agents and microbiological effects, except for the action of dilute alkalis. **Polyacrylonitrile fibers (PAN)** are resistant to oils, acids, organic solvents and stable under nuclear radiation. Treatment of polyacrylonitrile fibers with alkaline hydroxide solutions releases ammonia and produces a soluble polyacrylic acid salt. **Polypropylene (PP)** and **polyethylene (PE) fibers** are resistant to acids and alkalis and are insoluble in organic solvents at room temperature. **Polyvinyl chloride (PVC) fibers** are resistant to alkalis, acids and most organic solvents. [7][8][9][10]

#### **2.3.1. The Influence of Acids, Alkalis and Organic Solvents on Polyester Fibers**

Weak acids have no effect on polyester fibers, except when the fibers are exposed for prolonged periods. They also exhibit good resistance to strong acids at room temperature. However, long-term exposure of fibers to boiling HCl or 96% H<sub>2</sub>SO<sub>4</sub> results in their degradation. [11]

Polyester fibers show good resistance to weak alkalis even at elevated temperatures. They display moderate resistance to strong alkalis at room temperature, while at higher temperatures degradation occurs. Ionizable alkalis, such as caustic soda (KOH) and limewater (aqueous solution of Ca(OH)<sub>2</sub>), affect only the outer surface of polyester filaments. In contrast, primary and secondary alkalis and

ammonia can diffuse into the interior of polyester fibers, potentially causing cleavage of the polyester chain molecules through amide formation. [11]

Polyester fibers are resistant to organic solvents; chemicals used for cleaning and stain removal do not damage them. However, exposure to hot cresol or a mixture of phenol with chloroform can cause degradation or dissolution of this type of fiber. [11]

Table 1 shows the resistance of various types of natural and synthetic fibers to acids and alkalis.

*Table 2: Fiber Resistance during Treatment with Acids and Alkalis*

Fiber Type	Resistance to Acids	Notes	Resistance to Alkalis	Notes
<b>Cotton</b>	Very poor	Degraded by acids	Good	Swells and mercerizes in 10% NaOH
<b>Flax</b>	Poor	Greater resistance compared to cotton	Satisfactory	Less resistant compared to cotton
<b>Wool</b>	Good	Action of weak acids causes felting; concentrated hot acids cause degradation	Very poor	Weak alkalis cause felting; concentrated alkalis cause degradation
<b>Silk</b>	Good	Slightly less resistant compared to wool	Poor	Better resistance compared to wool
<b>Polyamide (PA)</b>	Satisfactory	Concentrated acids damage and decompose fibers	Good	Only concentrated alkalis damage them, especially 10% NaOH
<b>Polyester (PES)</b>	Good	Concentrated acids, especially H <sub>2</sub> SO <sub>4</sub> , damage fibers	Good	Concentrated alkalis cause degradation
<b>Polyacrylonitrile (PAN)</b>	Good	Soluble in HCl	Good	Only concentrated alkalis damage them, especially 10% NaOH
<b>Polypropylene (PP)</b>	Very good	Resistant, except to HNO <sub>3</sub>	Very good	Only concentrated hot alkalis cause damage

### 3. METHODS OF FIBER IDENTIFICATION

Various procedures are used for fiber identification:

- burning test;
- dry distillation of fibers;
- solubility of fibers in mineral and organic solvents;
- luminescence under ultraviolet light;
- light microscopy method;
- microchemical reactions;
- dyeability of fibers, etc. [8]

#### 3.1. Identification of Textile Fibers by Burning

The **burning test** is a method that involves igniting a fiber sample in order to observe its behavior during burning (Figure 3). This can help in the rapid identification of different fibers based on characteristic burning patterns, the odors released during combustion and the residue remaining after burning. Table 2 presents the behavior of textile fibers when subjected to heat and flame exposure. [1][8]



*Figure 15: Burning Test for Textile Fiber Identification*

*Table 3: Identification of Textile Fibers Using the Burning Test – Behavior under the Influence of Heat and Flame*

Type of Fiber	Burning Behavior	Odor During Burning	Burning Residue
<b>Cotton</b>	Burns quickly with a steady, light bluish flame, without melting	Smells like burning paper	Light (white) or gray fluffy ash
<b>Flax and Hemp</b>	Ignites easily, burns rapidly	Smells like burning paper	Gray ash that crumbles easily
<b>Viscose</b>	Ignites easily, burns without soot	Smells like burning paper	Hard, glassy, dark gray residue
<b>Wool</b>	Ignites slowly, burns with a weak flickering flame without soot, self-extinguishes outside the flame	Smells like burning hair	Black shapeless, brittle mass
<b>Silk</b>	Burns with a weak flame, self-extinguishes outside the flame	Smells like burning hair	Black fragile residue
<b>Acetate Fibers</b>	Burns rapidly while melting	Vinegar-like (acidic) odor	/
<b>Polyamide Fibers</b>	Burns weakly, melts, self-extinguishes outside the flame	Unpleasant odor like celery or pyridine	Hard, dark brown residue
<b>Polyester Fibers</b>	Melts, burns with black smoke, without flame	Sweet odor	Hard, glossy dark bead
<b>Polyacrylic Fibers</b>	Ignites easily, burns rapidly with sooty flame, without melting	Sharp odor	Black brittle bead
<b>Polyvinyl Chloride</b>	Does not ignite, does not burn; melts in flame releasing soot	Sooty or smoky odor	Black hard resinous bead
<b>Polyvinyl alcohol</b>			
<b>Polypropylene</b>	Ignites and melts easily, burns rapidly without soot, with little or no visible flame	Irritating odor	Hard dark residue
<b>Polyethylene</b>	Burns slowly	Candle-like odor	Hard bead
<b>Asbestos</b>	Does not ignite or burn	/	/
<b>Glass Fibers</b>			
<b>Elastane</b>	Burns like rubber	Smells like burning rubber	Dark residue

### 3.2. Identification of Fibers by Analysis of Gaseous Decomposition Products – Dry Distillation

**Dry distillation** is based on the analysis of decomposition products formed when fibers are heated to their boiling temperature. The gaseous decomposition products can be of an alkaline or acidic nature, which is determined using red or blue litmus paper. The presence of sulfur compounds is determined using lead acetate paper. Table 3 presents a comparative analysis of textile fiber identification based on the examination of decomposition products. [9]

*Table 4: Comparative Overview of Textile Fiber Identification by Analysis of Decomposition Products (Dry Distillation)*

Type of Fiber	Dry Distillation
Cotton	Acidic products; blue litmus paper turns red
Wool	Alkaline products; red litmus paper turns blue
Silk	Alkaline products; red litmus paper turns blue
Flax and Hemp	Acidic products; blue litmus paper turns red
Viscose	Acidic products; blue litmus paper turns red
Polyacrylic Fibers	Alkaline products; red litmus paper turns blue
Polyester Fibers	Acidic products; blue litmus paper turns red
Elastane Fibers	Alkaline products; red litmus paper turns blue
Polyacrylonitrile Fibers	Alkaline products; red litmus paper turns blue
Polyethylene and Polypropylene Fibers	Neutral
Polyvinyl Chloride Fibers	Acidic products; blue litmus paper turns red

### 3.3. Solubility of Fibers in Mineral and Organic Solvents

Dissolution is a physical process in which a solvent breaks down the molecules and the bonds between the molecules of the substance being dissolved. When textile fibers are treated with appropriate solvents, it is possible to identify them based on their chemical composition. The solubility depends on the chemical structure of the fibers and the presence of –OH, –COOH and –NH<sub>2</sub> groups within the fibers, as well as the structure of the fibers themselves. Table 4 shows a comparative analysis of textile fiber identification according to their solubility in mineral and organic solvents. [9]

*Table 5: Comparative Overview of Fiber Identification Based on Solubility in Mineral and Organic Solvents*

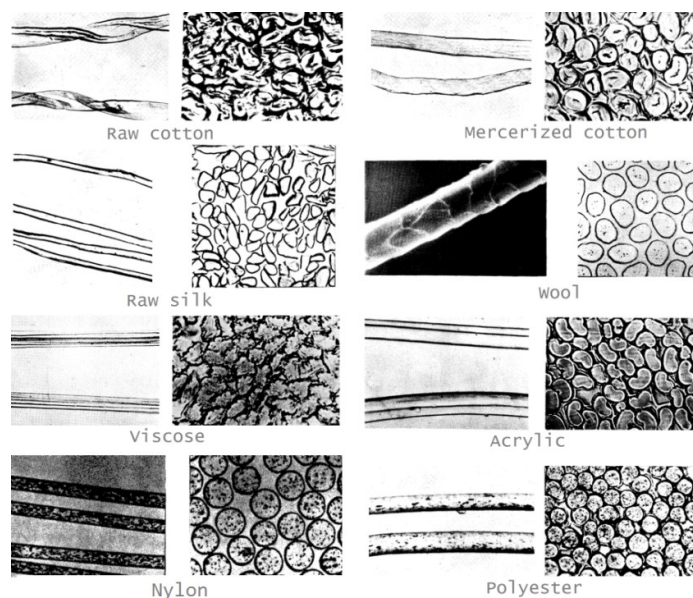
Type of Fiber	Solubility
Cotton	Swells in copper-ammonium oxide solution in the form of a “pearl necklace” and dissolves
Wool	Soluble in hot 5% NaOH and NaOCl <sub>2</sub>
Silk	Soluble in ZnCl <sub>2</sub> , 90% formic acid and hot 5% NaOH
Flax and Hemp	Swells and dissolves in copper-ammonium oxide solution
Viscose	Swells and dissolves in copper-ammonium oxide solution
Polyacrylic Fibers	Soluble in hot acetic and formic acid and in hot dimethylformamide
Polyester Fibers	Soluble in hot phenol and nitrobenzene
Elastane Fibers	Soluble in Cl-Zn-J solution
Polyacrylonitrile Fibers	Soluble in 70% Ca(SCN) <sub>2</sub> , hot dimethylformamide and cold HNO <sub>3</sub>
Polyethylene and Polypropylene Fibers	Soluble in hot xylene
Polyvinyl Chloride Fibers	Soluble in chloroform, acetone and phenol

### 3.4. Identification of Textile Fibers by Microscopy

**Microscopic analysis** is a method for the detailed observation of fibers under a microscope. To observe a longitudinal section of a fiber, it is cut and placed on a microscope slide, after which a drop of distilled water is placed over the fiber. A cover slip is then carefully applied at a sharp angle, allowing the liquid to spread evenly along the slide, until the cover slip rests completely on the slide. For observing the cross-section of fibers, the easiest preparation method uses a cork stopper. The fibers are first aligned parallel to each other and then threaded through the cork using a needle and thread. A thin slice of cork is cut with a razor blade and a circle is marked around the sample with a marker to facilitate locating it under the microscope (Figure 5). Table 5 provides instructions for the identification of textile fibers using the microscopy method. [1][9]

*Table 6: Microscopic Identification of Textile Fibers*

Type of Fiber	Micromorphological Characteristics of Textile Fibers	
	Longitudinal Appearance	Cross-Section
<b>Cotton</b>	Twisted ribbon	Kidney-shaped, bean-shaped
<b>Wool</b>	Characteristic scales	Round or slightly oval
<b>Silk</b>	Smooth surface	Triangular with rounded corners
<b>Viscose</b>	Striations	Round, slightly serrated
<b>Polyacrylic Fibers</b>	Smooth surface	Round, oval
<b>Polyester Fibers</b>	Smooth surface	Round



*Figure 16: Micromorphological Characteristics - Longitudinal Appearance and Cross-Section*

### 3.5. Identification of Textile Fibers Based on Differential Dyeing

The **xanthoproteic reaction** is used to detect the presence of aromatic amino acids such as phenylalanine, tyrosine and tryptophan in the protein molecule. Heating a protein solution with concentrated nitric acid forms a yellow precipitate. When sodium hydroxide solution is added to the precipitate, the yellow color changes to orange. Compounds containing a phenolic group react with **Millon's reagent** (a solution of mercurinitrite in 50% nitric acid), producing red-colored products. The only amino acid that gives this positive reaction is tyrosine, as well as its derivatives. **Schweizer's reagent** is an aqueous solution of copper(II)tetraammine hydroxide,  $[\text{Cu}(\text{NH}_3)_4](\text{OH})_2$ . It is used in the production of cellophane, nylon and cellulose derivatives, as cellulose is soluble in it. Acidifying a cellulose solution in Schweizer's reagent causes the cellulose to precipitate (Figure 6). The **Allwörden reaction** is a chemical reaction that occurs in wool and other animal fibers containing keratin. Under certain conditions, such as treatment with chlorine water, swelling occurs and bubble-like structures (Allwörden pockets) are formed. Table 6 presents the microchemical reactions used to identify textile fibers by their differential coloration in dye solutions. [8][9][12][13][14][15]

*Table 7: Identification of Textile Fibers Based on Differential Coloration in Dye Solutions*

Type of Fiber	Microchemical Reactions and Characteristic Coloration
<b>Cotton</b>	KJ – brown coloration, Cl-Zn-J – red-purple coloration
<b>Wool</b>	Xanthoproteic reaction with $\text{HNO}_3$ – brown color, Millon's reagent – orange coloration
<b>Silk</b>	Xanthoproteic reaction with $\text{HNO}_3$ – brown color, Millon's reagent – orange coloration
<b>Flax and Hemp</b>	Cl-Zn-J – dark purple coloration, Phloroglucinol – light pink coloration

<b>Viscose</b>	KJ – black coloration, Cl-Zn-J – bluish-red/purple coloration
<b>Polyacrylic Fibers</b>	KJ – black coloration, Cl-Zn-J – yellow coloration
<b>Polyacrylonitrile Fibers</b>	Cl-Zn-J – yellow coloration

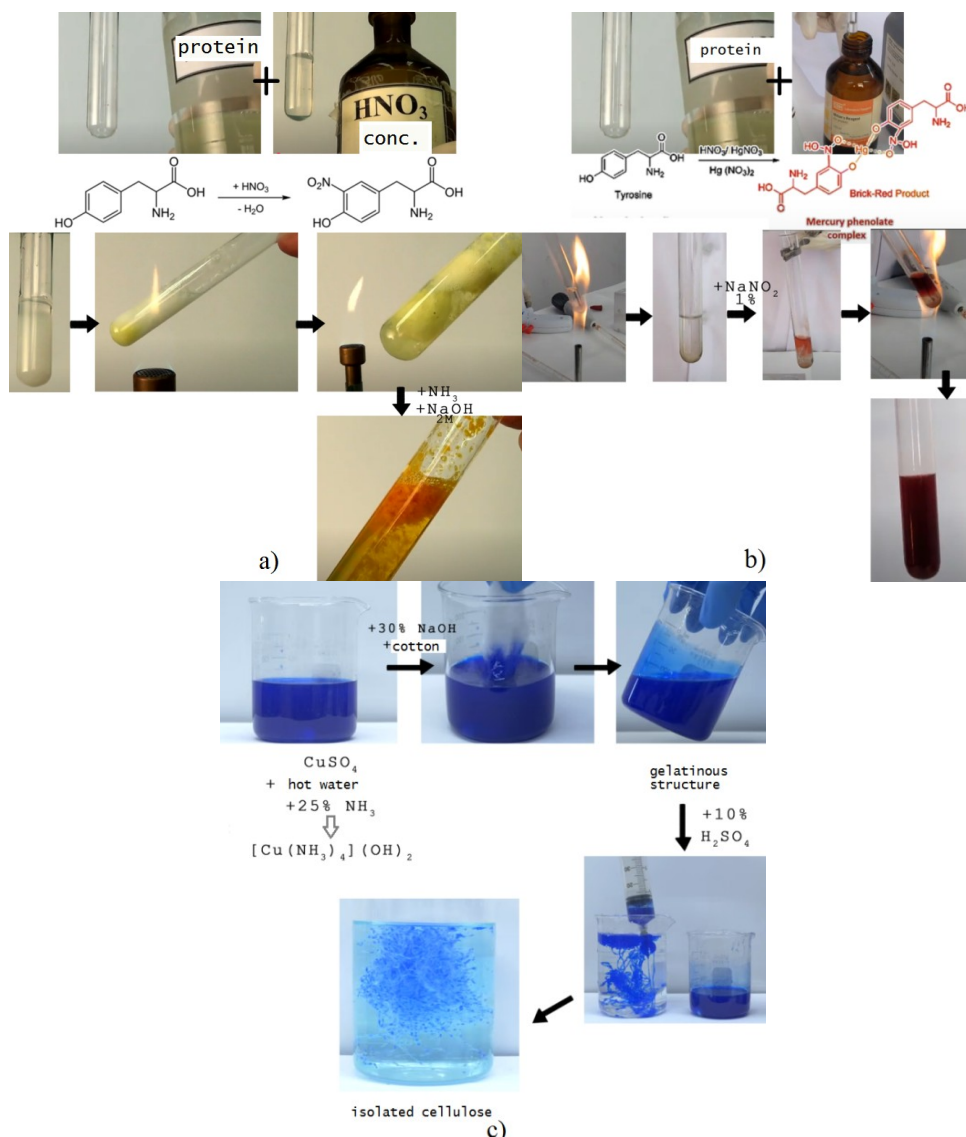


Figure 17: Identification of Textile Fibers Based on Differential Coloration in Dye Solutions: a) Xanthoproteic reaction, b) Millon's reaction and c) Extraction of cellulose using Schweizer's reagent

#### 4. DISCUSSION

**Chemical testing** of textile fibers, which provides insight into their durability and performance, is essential to maintain the quality of finished products in accordance with standards and to protect the environment. Textile fibers of plant origin contain *cellulose*, which is unstable under the action of concentrated acids; this leads to the hydrolysis of glycosidic bonds and the disintegration of fibers. In contrast, these fibers retain stability in dilute alkaline environments. Treatment of fibers with 18–25% NaOH - known as mercerization - produces fibers with increased luster, strength, absorbency and improved hand feel. *Protein* fibers are relatively resistant to weak acids, during which felting occurs. Concentrated acids, however, destroy them. Strong alkalis hydrolyze polypeptide chains, break salt

linkages and hydrolyze disulfide bonds. *Synthetic* fibers showed greater overall chemical resistance, although certain reagents - such as strong oxidizing agents or concentrated alkalies - can cause surface etching or partial hydrolysis. These tests confirm that the chemical resistance of fibers is largely determined by their functional groups, degree of polymerization and molecular orientation.

In the context of **fiber identification**, the *burn test* quickly determines the type of fiber based on its characteristic odor, type of residue and flame behavior: cellulosic fibers give off the smell of burning paper and leave a soft gray ash; protein fibers smell like burning hair and leave a brittle ash; most synthetic fibers melt and form hard beads. This method, however, is not sufficiently precise when examining blends or chemically modified fibers. In *microscopic examination*, the longitudinal appearance and cross-section are key to distinguishing fibers: the twisted ribbon-like shape of cotton, the characteristic scales of wool, the smooth filament of silk and the uniform circular or trilobal cross-sections of synthetic fibers - indicate the fiber's origin and production method. Nevertheless, microscopy alone cannot reliably identify fibers with similar surface characteristics. *Solubility tests* provided additional means of differentiation, since each fiber type showed specific behavior in certain solvents. For example, cellulose dissolved in a copper oxide-ammonia solution, while protein fibers were sensitive to sodium hypochlorite and sodium hydroxide. Synthetic fibers displayed variable solubility patterns: polyester dissolved in phenol, while nylon dissolved in formic acid. By combining data on chemical reactivity and solubility, more precise fiber identification was achieved.

## 5. CONCLUSION

The action of various chemical agents - such as acids, alkalies, oxidizing or reducing substances - can have a significant impact on the structural properties and other characteristics of fibers. Some fibers exhibit high resistance, while others are more or less susceptible to damage or complete degradation. Methods such as burn testing, dissolution in specific solvents, microscopic analysis and dyeing reactions, enable precise determination of fiber type, thereby facilitating their classification and processing. Understanding the reactivity of fibers with chemicals and the ability to accurately identify them, forms the foundation for the further development of modern and functional textile materials. These findings confirm the importance of chemical testing as a cornerstone of textile quality control and material identification, while also highlighting the potential for future innovations in environmentally sustainable and automated fiber analysis techniques.

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# CREATIVE ENTREPRENEURSHIP IN THE TEXTILE INDUSTRY

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## ABSTRACT:

*Modern entrepreneurship should prioritize creativity, as it enhances our understanding of the entrepreneur's work processes and contributes to business improvement. The analysis demonstrates that entrepreneurship has significantly expanded in recent times, along with the development of contemporary marketing strategies and methods for defining target audiences. Additionally, the impact of entrepreneurship on fashion design is highlighted, emphasizing that learning about entrepreneurship is more effective when it is rooted in creative and practical experiences. This approach also fosters the development of new connections, allowing entrepreneurs to meet individuals who can share innovative ideas, become partners, collaborate on product sales, and engage in shared marketing efforts. These interactions generate interest in the product being offered.*

*Keywords: Creative entrepreneurship, target audience, consumers, marketing, product.*

## 1. INTRODUCTION

Creativity is not a new phenomenon, however, its relationship with the economy is a more recent development, along with the emergence of activities that generate added value and wealth. Entrepreneurship is a complex and demanding process, and launching a business requires acquiring a range of knowledge and skills. It is essential to learn basics of the marketing and how it functions, especially in the fashion industry. Special attention should be paid to selecting the target audience for whom the clothing item is designed. Additionally, it is important to identify elements that will capture their attention and interests. Furthermore, developing effective strategies for successful product sales and market positioning is crucial. Alongside product selection and target audience identification, it is vital to recognize the significant role of social media in promoting our products. Various programs and tools, combined with social networks, can effectively showcase our ideas or videos to customers. This approach allows us to engage our specific target audience and encourage them to purchase our products.

## 2. TARGET AUDIENCE

The first step to consider is identifying our specific target audience to whom we would be selling our product or service. In the textile industry, the target audience can be defined based on various consumers characteristics, it cannot be viewed as a single, uniform group since customers needs and desired are different. Clearly defining the target audience allows companies to better tailor their products and marketing messages.

### 2.1. Demographic segmentation

Demographic segmentation serves as the foundation for understanding the textile market. The first criterion is gender, as many companies focus exclusively on men's, women's or children's clothing. The second criterion is age, which includes different age groups such as youth, families, older

generations and more. The third criterion is social class, belonging to a specific social class often reflects a unique lifestyle and a particular clothing style.

## **2.2. Behavioral segmentation**

Behavioral segmentation categorizes consumers based on their purchasing behavior and product usage. It examines whether purchases are impulsive or planned, made online, or in physical stores, and how frequently consumers shop. Some consumers exhibit high loyalty to certain brands, while others constantly seek new options. Additionally, some prioritize comfort, while others focus on quality or affordability.

## **2.3. Geographic segmentation**

While the textile industry often operates on global scale, is also crucial due to local factors. Climate plays a very significant role, as the need for winter or summer clothing depends on geographic locations. One of the important geographic segmentations is cultural influences and fashion preferences can vary significantly across different regions.



*Picture 1. It shows what is target audience.*

## **3. THE IMPORTANCE OF SOCIAL MEDIA**

Social media offers valuable opportunities to reach out target audience more effectively. As these networks have gained immense popularity, marketing has naturally expanded onto these platforms. They have become an essential tool for enhancing a company's visibility and boosting product sales, facilitating online transactions alongside traditional in-store purchases. Platforms such as Facebook, TikTok, Instagram, Email and various websites play a crucial role in promoting products and services. Products can be showcased through images that include detailed description about aspects like size, material, and color. Additionally, videos can present the product in an engaging manner. Promotion

can also be conducted by influencers or celebrities, who can significantly elevate a product's popularity, it can be organized a giveaway content that can elevate a products and brands popularity, it can be done by a promotion through adds, videos on YouTube that can show a process of making a product. Furthermore, there are sales applications that can help streamline online transactions. While there are many ways to promote products, it is essential to utilize editing software for videos and images. Everything needs to be created with precision and attention to detail to ensure that nothing is offensive to potential customers. Popular editing programs include Photoshop ( for editing pictures), Canva (make interesting presentations, animations and other.), CapCut (an application that helps in editing videos, adding texts, making better picture and other...), and Vita (it is almost the same as CapCut), and a lot other application. Moreover, social media platforms employ algorithms that monitor consumer behavior. This allows for targeted outreach, as users who have previously searched for specific types of products are more likely to see similar items, including ours. Consumers can also



share videos and images of products they find appealing, believing their friends or family might like them too. Overall, social media marketing is incredibly important and streamlines the process considerably. However, it does require a dedicated team to consistently post and promote products daily. A brief interruption in promotion can lead to a noticeable drop in consumer engagement.

*Picture 2. Shows a person making a video for social media.*

#### **4. TEAM OF PEOPLE**

A team of entrepreneurship typically consist of two or more individuals who share the responsibilities of running a business. Working together can make the process easier, with the entrepreneur, the founder of the company, playing a crucial role. The entrepreneur should have a solid understanding of entrepreneurship and provide guidance to ensure the business's success. Team members, or employees, contribute ideas that are developed collaboratively and put into practice. Additionally, advisors, such as accountants, legal associates, and marketing experts, offer important support. This team must have a clear common goal, support the business idea, and possess sufficient resources, particularly financial ones. Maintaining strong motivation is also essential for success. With the right encouragement and drive, the company can achieve significant success. However, for this to happen, team members must make decisions collectively, generate new ideas, adapt to market changes, and be willing to adjust plans as necessary. Persistence is key. Most importantly, the entrepreneur, as the

leader, must have special skills, particularly strong interpersonal skills. The entire team should be prepared to accept mistakes together and work collaboratively to address and solve them.

## 5. CREATIVE WORKSHOPS

These entrepreneurial textile workshops and training programs aim to engage participants and encourage them to start their own businesses. In these workshops, participants will learn about effective marketing strategies, essential entrepreneurial knowledge, and how to establish their own companies or workshops. The learning process will be particularly effective if participants select a product that is not currently popular. Throughout the workshops, participants will discover how to create a business name, design a company logo, and attend regular entrepreneurship classes. These classes will cover essential topics, including how to protect, produce, promote and establish a business, as well as how to sell a product. By the end of the program, participants will be given a specific deadline to complete their product while meeting all necessary criteria to ensure it is market-ready. During their training, participants will not only gain insight into how marketing works but also learn about the process of registering a business. They will become familiar with programs that can effectively support social media promotion and simplify marketing efforts. Additionally, participants will attend sewing workshop and other creative session such as embroidery, knitting, and crocheting, expanding their skill sets and knowledge for future product development. Participants will also have the opportunity to promote their product at a bazaar during the training period, serving as a first step in marketing their businesses. These workshops will foster connections with like minded individuals, allowing for the exchange of experiences and collaboration on future ideas and opportunities. Overall, participants will gain valuable knowledge, new connections, and hands on experience to assist them in launching their own businesses.

*Picture 3. People around the table working together.*



## 6. CONCLUSION

I can speak about creative entrepreneurship from personal experience, as i participated in a project called the ‘KUL Projekt’ – The Creative Industries Development Centre. This initiative was organized

in collaboration with Croatia and Slovenia, receiving significant financial support from the European Union. It was a rewarding and engaging experience that lasted two years, during which I gained extensive knowledge and made many valuable connections. Through this project, I learned that creativity can be expressed at any time and in any place, and that we can always introduce something new or improve existing ideas. With the support provided by the project, we received certificates confirming that we completed entrepreneurship training and were prepared to become independent and start our own ventures.

## 7. LITERATURE

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3. Picture number 2. Comes from this site [https://textilevaluechain.in/news-insights/how-to-use-social-media-to-market-your-textile-business](https://textilevaluechain.in/news-insights/how-to-use-social-media-to-market-your-textile-business;);
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## **DIGITAL TRANSFORMATION OF CLOTHING CONSTRUCTION: COMPUTER-BASED APPROACHES AND INNOVATIONS**

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### **Abstract :**

*The modern textile industry faces challenges of accelerated production, high market demands, and the need for sustainable use of materials. Traditional clothing construction methods, based on manual work and two-dimensional patterns, are becoming increasingly less functional in this context. Digital transformation, through the use of CAD/CAM software and 3D modeling, enables precise pattern construction, optimization of garment designs, visualization on virtual mannequins, and a significant reduction in production time and material waste. The use of software tools such as Lectra Modaris, CLO 3D, Optitex, and others facilitates process automation and bridges theory and practice in education, preparing students for contemporary work in the industry. Further development includes the application of artificial intelligence and 3D scanners for automated creation of custom patterns, further enhancing accuracy, productivity, and sustainability in textile manufacturing. This study explores the effects of digitalization in clothing construction, highlighting innovations, software applications, and potential directions for future development in both industry and education.*

**Key words:** digital transformation, clothing construction, software solutions, Lectra, Clo3D, sustainable production

### **1. INTRODUCTION**

The modern fashion industry faces the constant challenge of meeting demands for faster and more precise production. The conventional method of clothing construction is based on manual work and the development of patterns through multiple stages. This traditional approach is becoming increasingly less functional within the current market requirements. The digital transformation of clothing construction enables the automation of multiple stages in the process of pattern creation, modeling, and simulation for optimizing pattern piece placement. Software solutions used in digital garment construction, such as Lectra, Clo3D, and Optitex, provide precise pattern development and significantly reduce the product development timeframe. This leads to reduced material waste, improved material utilization, and enhanced communication between designers and production teams. The aim of this paper is to explore how digital technologies are transforming the process of garment construction, with a focus on software solutions such as Lectra, whose application is widely adopted in the textile industry. The paper will examine in detail the benefits of implementing computer-aided construction and software solutions in modern clothing design, emphasizing sustainable production and contemporary market needs.

### **2. HISTORICAL DEVELOPMENT OF CLOTHING CONSTRUCTION**

Clothing construction is one of the oldest crafts, developing alongside the needs of society and technological advancements. Two-dimensional materials such as fabric and leather were used to create patterns and templates, which were then shaped through sewing or draping to form three-dimensional garments. In this way, finished clothing was produced that adapted to the contours of the human body [1]. Clothing has existed since the emergence of the first civilizations [3]. Initially, garments were made entirely by hand, without precise pattern construction or anthropometric measurements, and pattern pieces were assembled manually. Clothing production relied heavily on experience, without excessive concern for perfection. Over the centuries, clothing construction evolved through different phases depending on geographical location and culture, with methods of garment creation changing accordingly. However, historical records, sketches, and templates vary due to knowledge being passed orally only between master and apprentice. Successful constructions served as a foundation for further development [1]. Looking across the centuries, from the earliest civilizations to the modern era, early societies produced garments from natural materials as well as animal skins. The Egyptians demonstrated their tailoring skills through simple geometric shapes, and both construction techniques and the

garments themselves varied depending on purpose—whether for religious ceremonies, funerary rites, or everyday use. Egyptians shaped fabric through draping to achieve the desired form, resulting in clothing that closely followed the body's contours. During the Middle Ages in Europe, tailors held a significant social role. They began creating basic templates known as "blocks" or "slopers," which could be adapted to individual client measurements. With the development of arts and culture during the Renaissance, and contributions from Leonardo da Vinci and his colleague Albrecht Dürer, who studied human proportions and anatomy, greater attention began to be paid to body measurements and dimensions, improving garment construction. The discovery of new maritime trade routes led to the exchange of goods, materials, experience, and knowledge. Prior to the Industrial Revolution, tailors worked with great precision, focusing on both comfort and functionality. Clothing was made to individual client measurements and involved complex constructions [2]. At this time, tailors had not yet adopted pattern-based construction, instead transferring designs to material manually with chalk [1]. Garments with complex constructions and multiple details were accessible only to the wealthy. At the end of each season, patterns were often destroyed, with knowledge remaining solely between master and apprentice—a principle that persisted until the onset of the modern era [1]. The 18th century marks the beginning of the Industrial Revolution, widely considered a turning point that brought numerous advances across many industries, including the textile industry. Even then, precise measurements remained essential for clothing production. Garments were relatively simple in design and construction, often taking a small, block-like form. Tailors experimented to achieve perfection based on knowledge acquired from masters and colleagues. Later, each country standardized patterns and measurements to achieve consistent results. Soon thereafter, the first textile schools were established, making knowledge and skills more widely accessible. One of the first books on clothing construction and modeling was the "Book of Spanish Tailors" (Libro de Geometría Partica y Traca), which served as a source of contemporary knowledge on cutting, construction, and modeling [1–3].

### 2.1. Traditional method of clothing construction

The traditional method of clothing construction, still applied today in schools during clothing construction and modeling classes, as well as in ateliers and tailoring workshops, has been used since the establishment of the first textile schools and continues to the present day. This method involves geometric construction on paper and represents the classical approach to garment pattern making. Initially, the tailor measures the model to obtain the basic measurements, and then calculates auxiliary measurements using formulas and the basic data. Only after determining these auxiliary measurements can the construction process begin. The hand-made pattern is created on pak paper in full scale. Pak paper, typically brown or white kraft paper, is suitable for pattern making due to its durability. It resists tearing during multiple adjustments, has good flexibility, and can be shaped precisely, making it ideal for accurate pattern formation. Pencil marks on pak paper remain visible, which is essential for precise construction. The basic pattern is drawn using rulers, triangles, and French curves, and often with the help of pre-made cardboard templates, representing both the front and back parts of the garment. At the beginning of the construction process, lines for the bust, waist, and hips, as well as auxiliary lines, are marked. Then the tailor proceeds to shape the front and back parts and model the garment. Modeling is the final stage of pattern making and is performed over the basic pattern by attaching or sewing additional paper pieces, or by cutting or opening existing lines. Seam allowances, usually 1–1.5 cm, are added at the end [4].

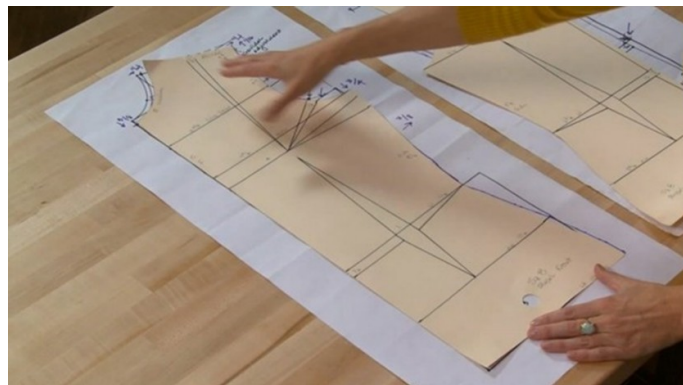
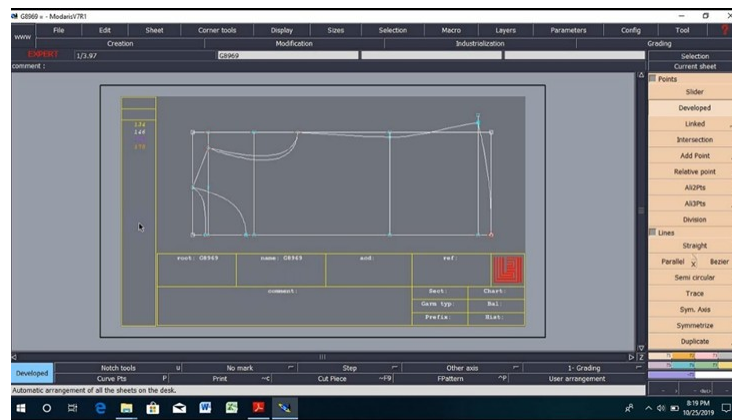


Figure 1.2. Hand-made clothing construction

### 2.1 Advancements in computer-aided clothing construction: computer-based transformation

In the 21st century, technology has experienced significant advancement, profoundly changing the way work is conducted across various sectors. As smart technology has become an indispensable part of the modern era, it has inevitably influenced the textile industry as well. To minimize the time from concept to realization of a garment, maximize material utilization, and reduce waste, garment construction has been enhanced through CAD software (Computer-Aided Design). CAD software is applied in clothing construction and modeling, as well as in pattern making for garments. Instead of slow manual construction on paper, CAD software enables precise creation of custom patterns and easy modeling of various designs. With the help of CAD tools, size adjustments and design modifications can be performed quickly and efficiently. It also allows automatic grading and adaptation, as well as 3D visualization, significantly reducing production time and material consumption [4]. In addition to CAD/CAM systems, other software used in computer-aided clothing construction includes Lectra Modaris, widely employed in the textile industry; Optitex, a 2D tool that enables 3D simulation; TucaCAD, a CAD software for construction and technical drawing, modeling, and visualization; and many others [5–6]. Auxiliary software and applications for creating technical and fashion sketches include Adobe Illustrator, Photoshop, Sketchbook, and CorelDRAW, which can also be used for garment construction.



*Figure 2.2. Pattern making in Lectra Modaris*

### 3. COMPUTER TOOLS IN CLOTHING CONSTRUCTION

With increasing market demands, software tools have been implemented to support more efficient and precise garment production. It is no longer sufficient for clothing to be merely functional and ready for use; it must also be accurately sewn. To ensure that garments are aesthetically appealing and well-tailored, precise construction and modeling are required, with software tools playing a key role. Traditional methods such as hand construction and modeling have gradually been replaced by newer, more functional digital approaches that accelerate production, minimize errors, and optimize material and time usage. The demand for personalized clothing is rising, and digital technologies are shaping the future of garment development. This has led to the implementation of CAD/CAM systems. CAD (Computer-Aided Design) is a computer-supported design system that enables precise garment construction and modeling, as well as monitoring cutting processes and automated data distribution. When using CAD software, virtual garment simulations are conducted, and prototypes are created to serve as the basis for final product manufacturing. The software allows work in both 2D and 3D environments, which act as virtual spaces where garment pieces are tested before physical production [7]. In addition to CAD/CAM systems, software such as Gerber, Lectra, Optitex, and CorelDRAW are used for graphic applications in professional settings. CAD/CAM systems are promising because they optimize resource usage, enable precise cutting, and create a mutually beneficial relationship between manufacturer and consumer. They also provide designers with creative freedom without the need for physical alterations and sewing, saving both time and money [8–12].

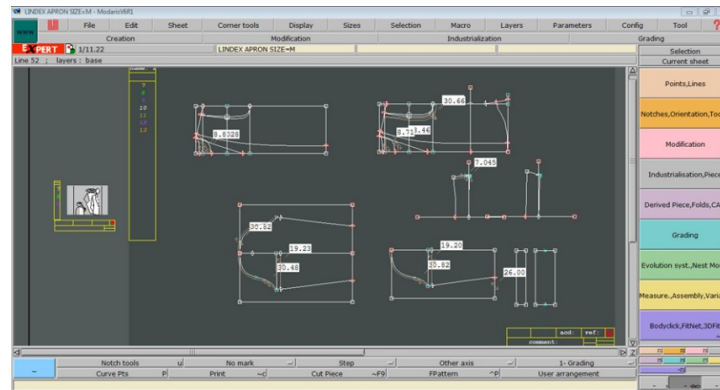


Figure 3.3. Pattern making and size grading using Lectra software

#### 4. DIGITAL REPRESENTATION OF TOOLS IN COMPUTER-AIDED CLOTHING CONSTRUCTION

Computers occupy a significant role in modern clothing construction. With just a few simple mouse actions, it is possible to modify a design, adjust shapes, and generate a realistic digital prototype. Lectra is among the most well-known CAD software programs used in the fashion and textile industry, intended for digital garment construction and modeling, as well as for size grading and pattern creation. According to research from 2024, 70% of users of other digital construction programs switched to Lectra Modaris. The software interface does not have a fully intuitive menu, which can make independent navigation challenging. Therefore, additional support in the form of guides or tutorials is often necessary to help beginners familiarize themselves with tools and functions [16] (According to: "Facilitando a Transição: Audaces e Lectra em Foco," 2024). Lectra Modaris is the primary software for 2D garment construction and modeling, and it includes an additional Modaris 3D Fit module for 3D simulation on virtual avatars, enabling virtual fitting of models created in 2D Modaris. By using color displays, the software indicates potential issues such as excessive tightness or looseness of the fabric. For example, red may indicate a high-tension zone, while green signals optimal fabric tension, allowing the garment to be produced with maximum comfort. Using this software, real-life movements, such as sitting and walking, can be simulated. Material properties such as elasticity, thickness, and weight can be added during simulation, increasing the accuracy of garment behavior modeling. This program also facilitates e-commerce, saving both material during production and time and money for consumers and manufacturers [18]. During construction, it is important to accurately shape seam lines, provide additional ease for comfort, and follow the model's contours according to the technical sketch. Clo3D software allows practical garment construction and modeling in real time within a three-dimensional environment. It also enables transformation of the base pattern according to the designer's ideas, constructor requirements, and production team needs [13] (According to: "An approach to design solutions for garments using a CAD system," 2022). Clo3D allows garments to be displayed on avatars in realistic natural movement and fully translates ideas from traditional hand sketches into digital form. Designers no longer need to create multiple sketches of the same model in motion; instead, the software enables visualization from different angles and movements in 3D. While the actual feel and texture of the fabric cannot be fully reproduced, the software significantly speeds up design decision-making [14]. This tool also supports automatic size adjustment (grading) and automatic template creation, greatly simplifying the process. These features allow beginners and students working in computer-aided clothing construction to more easily master the software [15].



Figure 4.4. Creation of the pattern layout



Figure 5.4. Realistic 3D representation of a dress



Figure 6.4. Model viewed from different angles and in various movements in 3D representation

## **5. INNOVATIONS IN DIGITAL CLOTHING CONSTRUCTION**

As previously mentioned, 3D modeling is one of the key innovations in clothing construction. It involves testing garments on virtual 3D mannequins created in Lectra Modaris 3D, CLO 3D, Browzwear, and similar software [15]. Once the basic 2D pattern is created, the garment is transferred to a 3D model, where the 3D mannequin “wears” the virtual clothing, simulating the garment’s actual appearance. Seam lines and body shapes are automatically measured, and the pattern is adjusted through mathematical algorithms, enabling mass customization of garments [16]. With advancements in information technology and the advent of artificial intelligence (AI), the textile industry has seen significant progress. AI applications in textiles encompass multiple stages of the production process. AI can be involved in fabric preparation, final finishing, and quality control, as well as in design ideation and providing fashion solutions. AI enhances productivity by automating work processes, increases accuracy, and supports more efficient resource management. In management and logistics, AI aids in production planning, inventory management, and risk prediction, while in manufacturing, AI-enabled machines produce goods faster using sensors and algorithms. In quality control, AI can detect defects in materials more quickly than the human eye through image analysis [19]. Although AI implementation in the textile industry offers numerous benefits, potential challenges must be considered. Initial implementation costs are very high, and many companies lack the financial resources to adopt AI, making implementation almost impossible in some cases. Employee training is crucial for developing smart manufacturing. Many workers are unfamiliar with advanced technological workflows, making workforce retraining necessary. AI also contributes to environmental sustainability by optimizing energy use and minimizing material waste. However, AI depends on data input, and incorrect or poorly structured data can lead to inaccurate results. Additionally, AI lacks built-in data protection, creating a risk that company data could be exposed to the public.

## **6. EFFECTS OF DIGITAL TRANSFORMATION IN CLOTHING CONSTRUCTION ON EDUCATION**

Digital transformation in clothing construction has brought a revolution to education. The introduction of CAD/CAM systems and software tools has modernized teaching processes. Students and pupils no longer rely solely on manual pattern making; instead, they can develop their digital skills in computer-aided construction and both 2D and 3D modeling. Through practical exercises, students can connect theory and practice, visualizing the effects of changes in garment construction, which prepares them for professional work after graduation. This approach also increases teaching efficiency, as it aligns with the production of sustainable fashion. Additionally, newer generations “digital-age children” show greater attention and interest in classes on digital clothing construction, as this method often maintains engagement more effectively. Errors can be easily corrected with a click, and mastering tools and options is straightforward. From a psychological perspective, this positively impacts students’ well-being, boosting self-confidence while fostering imagination and creativity, further stimulating their motivation to learn.

## **7. PROPOSAL FOR FURTHER DEVELOPMENT**

Digitalization and smart technologies are advancing day by day. It is not unlikely that, in the future, smart technologies may fully replace traditional production methods, and perhaps even human labor. One of my proposals for further development is the automated creation of patterns using AI and scanners—ScanToFit.AI. With the help of artificial intelligence, a model’s body could be scanned using a smartphone or a 3D body scanner. AI would recognize the body measurements without the need for manual measuring or calculation of auxiliary measurements. The scanner equipped with AI would be connected to a computer running software for digital garment construction, optimized to support AI integration. Size Stream provides 3D scanners connected to CAD software, while 3DLOOK allows scanning via a mobile phone. CLO 3D and Optitex support work with 3D avatars and import data from scanners, facilitating the creation of an integrated system. Based on all the data collected through scanning, the information would be automatically sent to the system, which would independently generate garment constructions or even ready pattern pieces. In a fully developed software workflow, once pattern pieces are prepared for printing, the data would be sent to another computer connected to a CNC fabric-cutting machine, which would automatically cut the fabric pieces according to the received specifications.

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# THE INFLUENCE OF ARTISTIC MOVEMENTS ON THE FASHION OF THE 20TH CENTURY

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## ABSTRACT

*This paper analyzes the Art Deco movement and its influence on 20th-century fashion. It discusses the origins and key characteristics of Art Deco, emphasizing its geometric forms, luxury, and modern aesthetic. The paper explores how these elements shaped fashion in the 1920s, particularly through changes in silhouettes, materials, and women's style influenced by social and cultural change. It also highlights the lasting impact of Art Deco on contemporary fashion and design.*

**Key words:** Art Deco, 20th century, design, flapper style, luxury.

## 1 1.INTRODUCTION

Fashion and art share a common framework when it comes to creating a relationship between the work of art itself, its creator, the audience, and aesthetic pleasure.

The art movements of the 20th century developed in response to social, political, and technological changes that shaped perceptions of the beauty, individuality, and purpose of art. These movements had a direct impact on fashion, thus shaping the aesthetic appearance of clothing throughout the decades of the 20th century. The most influential trends that shaped the fashion of the period were Cubism, Futurism, Art Deco, and Pop Art.

This seminar paper theoretically explores and analyzes the Art Deco art style, its appearance, place of origin and the influence it had on the fashion of the 20th century. The Art Deco style stands out for its elegance, luxury, and vibrant colors that have become synonymous with the popularity of the period. Unlike the Victorian era, which favored flowing silhouettes with accentuated large breasts, narrow waists, and rounded hips, the fashion of the 1920s brought a newfound simplicity, with a wealth of colors and materials that defined the period.

Art Deco, an abbreviation of the French term Arts décoratifs, is a style of visual arts, architecture, and product design that first emerged in Paris during the 1910s.

Art Deco takes its name from the International Exhibition of Art, Decoration and Modern Industry held in Paris in 1925. This style derives from the bold geometric shapes of Viennese Art Nouveau and Cubism. The renewal of interest in this exhibition, as well as in decorative modern art, was part of the global phenomena that marked the beginning of the end of the dominance of the international style and avant-garde, and later socially necessary purism. From its inception, it has been influenced by the vibrant colors of Fauvism and Bruce Ballet, as well as exotic art styles from China, Japan, India, Persia, Ancient Egypt, and Maya.

## 2. HISTORY OF ART DECO

### *2.1. The emergence of Art Deco*

The Art Deco movement emerged in the early 1920s and lasted until the outbreak of World War II in 1939. This period has been described as "a breath of fresh air between the smoke of World War I, World War II, and the Great Depression."

The advent of mass production has allowed designers and artists to enhance the aesthetic appearance of everyday objects, such as ashtrays, watches, and buildings. The end result, characterized by a luxurious and appealing appearance, marked a time of renewed optimism after the Great Depression, as well as a celebration of progress and modern ideas.

This movement is marked by the struggle for women's rights, economic prosperity and significant technological improvements, all of which have contributed to the development of a new way of life – a life characterized by progressive modernity, luxury and leisure. The key themes of this movement are reflected in three classic fashion styles that represent the essence of Deco fashion.

This style is characterized by elegance, both in details and in the overall appearance – they are still famous pieces of furniture made in this style. Art Deco does not tolerate excess, whether in details, colors or shapes. Since it originated between the two world wars, the influence of technology and new materials is obvious, allowing it to continue to influence contemporary styles. You can notice the presence of this style in the details of buildings and houses, such as ceilings. An excellent example is the Empire State Building building (Figure 2.1.1). Today, this style is calmer and less conspicuous, but it is still present in many modern interior designs.



*2.1.1. Painting of the Empire State Building - one of many buildings made in the Art Deco style[3].*

### *2.2. Characteristics of Art Deco*

The most famous fashion trend of the 1920s was the so-called "flapper look." The length of the hair becomes less important, while short haircuts on the page with bangs take precedence. The head is decorated with luxurious ribbons, pearls, rhinestones and feathers. Corsets relax, and instead of emphasizing the waist, the focus shifts to the hips. Dresses are raised to the middle of the calf and knee, while trousers are becoming more and more present in women's fashion, but in the form of wide legs. In addition to hair accessories, the emphasis is also placed on large, dangling earrings that reach

up to the shoulders. A bare back with low pearls, shoes on low heels, and the girls were dressed from head to toe in satin, chiffon, silk and tassels (Figure 2.2.1). For the first time, straight silhouettes and silhouettes of mermaids, as well as sleeveless dresses, appear. In addition to lightweight, luxurious materials, fur also appears on the fashion scene through vests and capes that adorn lavish evening dresses. Daily outfits were not complete without glass bell-shaped hats, decorated with ribbons.



*2.2.1. A picture of the fashion characteristics of the Art Deco style - beads, tassels, feathers and the like[1].*

In this glamorous environment, jewelry played a key role. Sapphires, diamonds and emeralds, worked in geometric shapes, hung from massive necklaces and earrings. Long pearl necklaces became especially popular thanks to Coco, who convinced the world that pearls don't have to be real and that fake ones are even better. This is also the time when women's rights began to be affirmed, which significantly influenced fashion, so the established dress code was violated. Women began to wear sportswear and pieces of men's cut. Actress Greta Garbo became one of the fashion icons of the 1920s, known as the Art Deco diva, while Louise Brooks, an actress and dancer from the shadows, popularized the bob hairstyle.

### **3. ART DECO – 20 century**

#### *3.1. The influence of Art Deco on the fashion of the 20th century*

The principles of Art Deco, which encompass geometric shapes, bold colors, and contemporary materials, continue to have a significant impact on modern design. Elements of Art Deco can be recognized in contemporary architecture, furniture, fashion, and graphic design, indicating the enduring legacy of this iconic style.

Although the popularity of the Art Deco movement declined after World War II, it underwent a resurgence during the 1960s and is still present in industrial design and fashion. In addition, a new appraisal for the Art Deco movement has led to the establishment of numerous foundations dedicated

to the restoration and preservation of architectural monuments built during the Golden Age of Art Deco.

New articles about clothing were also aimed at female consumers of the time. Although there is no fashion style that is specifically labeled as "art deco" (such as certain pieces of jewelry, decorative objects, or architecture), there is a contemporary way of dressing that lives in tandem with broader stylistic trends.

Evening dresses reflected the desire of ladies to dance without restrictions in dress. The dress usually rested on narrow shoulder straps and had slits along the thighs, allowing her complete freedom of



movement while performing "Charleston" (photo 3.1.1.) [12].

*3.1.1. A painting of the "Charleston" dance - an example showing how much more mobility women's dresses had.*

The fashion industry often relies on the Art Deco style for its timeless elegance and glamour. Designers incorporate elements such as beads, sequins, and tassels into their creations.

In addition to various details and decorations on clothing, women wore a lot of jewelry, thanks to the availability of costume jewelry. Elegant silhouettes and attention to detail reflect the spirit of Art Deco in contemporary fashion collections.



*3.1.3. The difference between the two versions is clearly visible, the women get luxurious creations decorated with feathers, pearls, fringes and the like, while the men's version remains dark and appropriate for gentlemen[12].*

#### **4. ART DECO-THE FUTURE**

##### **4.1. Details that survive**

Artists have found inspiration in ancient civilizations such as Greece and Egypt. Interestingly, objects made in this style were handmade, which showed the world their skill, precision and skill.

The original party of the decade, in which art, fashion, interior design and music really came under the umbrella of Art Deco, the prevailing aesthetic of the 1920s immediately evokes associations with a thin matchstick cigarette holder sandwiched between a pair of plush fingers adorned with jewels. One hundred years later, the fashion scene is reviving this era of artistic innovation, enjoyment, glamour and opulence with a new spirit[14].

The '22 fashion season brought Art Deco to the catwalks of London, Milan and Paris like never before, manifesting itself through maximalist shapes, rich fantasies and geometric patterns. Whether it's Bruno Sialelli's plush patterns at Lanvin or Ioon Ahn's reworked fantasies at Ambush, it's clear that this season has been dedicated to radiance[14].



*4.1.1 Fashion Week 2022 Fashion Show Images - A Few Examples That Illustrate the Way Global Fashion Companies Have Used Art Deco Art Deco Style in Their Collections[14].*

#### **5. CONCLUSION**

The Art Deco art movement is characterized by elegance, glamour and a lavish lifestyle. Flowing dresses, feathers, velvet, pearls and many other key features of this style depict a period when people enjoyed a relaxed mood. Night parties, dancing and frequent drinking were not the only things that

could be noticed. If you are a fan of luxurious life and nightlife, Art Deco is an artistic style that you should think about.

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