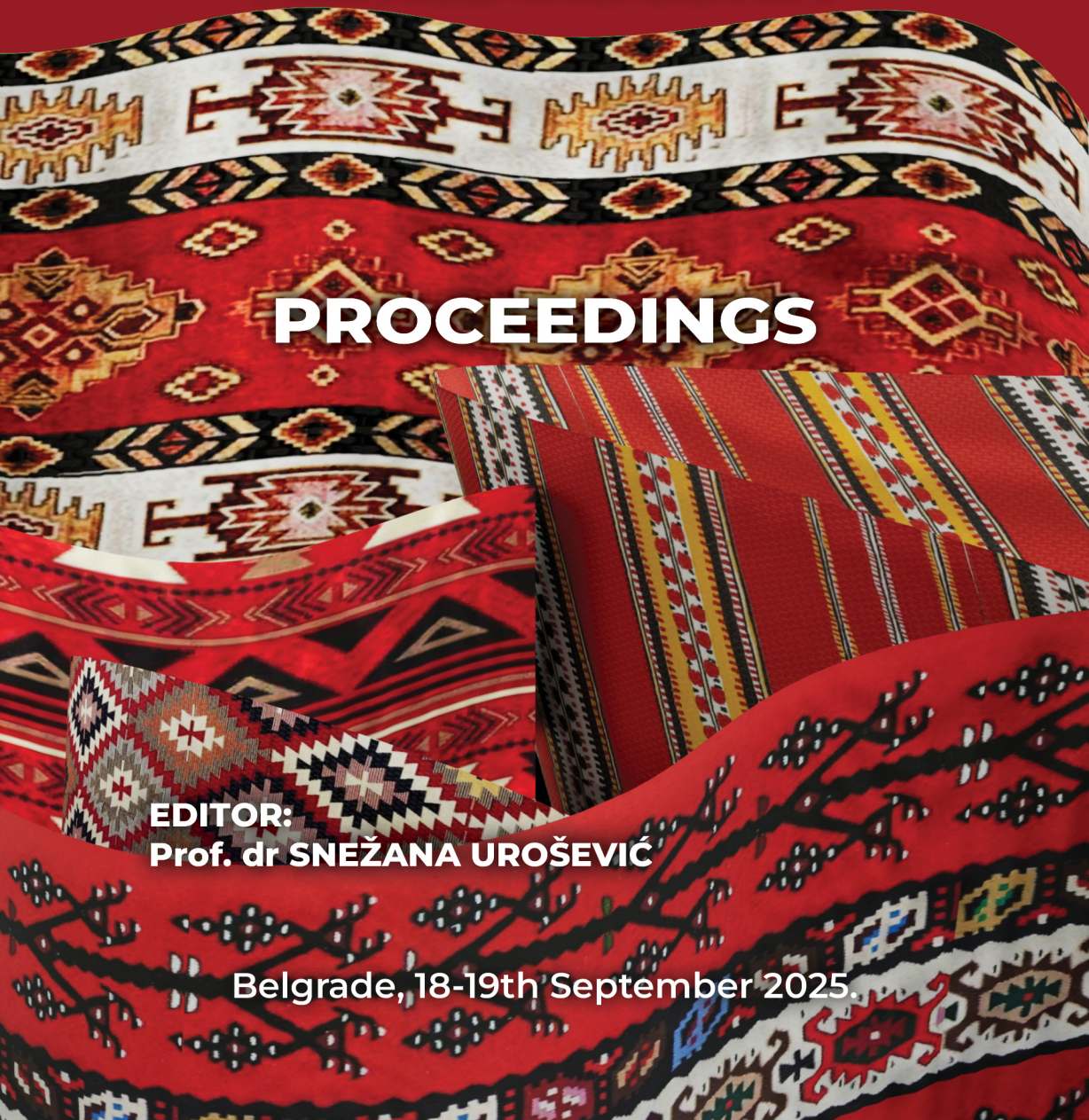
UNION OF ENGINEERS AND TEXTILE TECHNICIANS OF SERBIA

8th INTERNATIONAL SCIENTIFIC CONFERENCE

CONTEMPORARY TRENDS AND INNOVATIONS IN THE TEXTILE INDUSTRY



PROCEEDINGS

EDITOR:
Prof. dr SNEŽANA UROŠEVIĆ

Belgrade, 18-19th September 2025.

UNION OF ENGINEERS AND TEXTILE TECHNICIANS OF SERBIA

AND

UNION OF ENGINEERS AND TECHNICIANS OF SERBIA
FACULTY OF TECHNOLOGY AND METALLURGY IN BELGRADE
FACULTY OF TECHNOLOGY, SHTIP, NORT OF MACEDONIA
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PROCEEDINGS

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Belgrade, 18-19 th September, 2025
Union of Engineering and Technicians of Serbia
Home of Engineers „Nikola Tesla“

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PREFACE

The 8th International conference "Contemporary Trends and Innovations in the Textile Industry" CT&ITI 2025, is co-organized by:

- Union of Engineers and Textile Technicians of Serbia,
- Union of Engineers and Technicians of Serbia,
- Faculty of Technology and Metallurgy in Belgrade, University of Belgrade, Sebia,
- Faculty of Technology, Shtip, Goce Delchev University, North of Macedonia,
- Faculty of Mechaical Engineering, Polytechnic University of Tirana, Albania,
- Society for Robotics of Bosnia and Herzegovina and
- Balkan Society of Textile Engineering-BASTE of Greece.

The Ministry of Science, Technological Development and Innovation of the Republic of Serbia recognized the importance of this Conference, and thus, supported it.

The aim of this Conference is to consider current technical, technological, economic, ecological, R&D, legal and other issues related to the textile industry, then the application of contemporary achievements and the introduction of technical and technological innovations in the production process of fiber, textile, clothing and technical textile by applying scientific solutions in order to improve the business and increase the competitive advantages of the textile industry on the domestic and global market.

Leading scientists and experts from the Balkans and other countries, working at faculties, textile colleges and institutes, but also individuals who professionally deal with the issues at hand are taking part in this Conference.

The Conference program involves papers dedicated to the scientific and practical aspects of the following topics: Textile and Textile Technology, Textile Design, Management and Marketing in the Textile Industry and Ecology and Sustainable Development in the Textile Industry. The Conference program includes 42 papers, and a total of 108 participants from 10 countries: Bosnia and Herzegovina, Bulgaria, Croatia, Greece, India, North of Macedonia, Montenegro, Serbia, Slovenia and Turkey.

Therefore, this Conference is an opportunity for establishing scientific, educational and economic cooperation of our country with other countries. Certain number of papers by domestic authors present the project results dealing with fundamental research and technological development, financed by the Ministry of Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

I would like to thank all those who have made it possible to organize the conference Contemporary Trends and Innovations in the Textile Industry and make it a success. First, I would like to thank the Scientific and Organizing Committee for working hard, spending countless hours and finding the best solutions for numerous organizational aspects of our Conference. I also thank all the other institutions that supported the Conference in various ways, because without their support, the Conference could not have been organized. Last but not least, I would like to thank plenary lecturers, all authors and co-authors and guests for their participation in the Conference.

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PLENARY LECTURES

SOCIO-ECONOMIC ASPECTS OF CONTEMPORARY TRENDS IN THE DEVELOPMENT OF THE TEXTILE INDUSTRY

Original scientific paper
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ABSTRACT: *The intense technical and technological progress of recent decades has significantly influenced the transformation of economic activities across all sectors of business and everyday life. In many areas, this influence has been markedly positive, contributing to enhanced operational efficiency and improved living standards. However, over time, numerous adverse consequences of rapid growth and development, driven by the relentless pursuit of increased profits, have become increasingly evident. These negative outcomes primarily relate to environmental degradation, the accumulation of waste, the overexploitation of natural resources, and a general decline in quality of life. Humanity has gradually become aware that, if such trends persist, they may jeopardise not only future growth and development but also the very survival of our species. This awareness has prompted the formulation of new developmental models and strategies aimed at securing the long-term sustainable development of the global human community. This paper provides a theoretical overview of contemporary sustainable development concepts, with a particular focus on analysing key trends in the ongoing transition of the textile industry within both developed economies and developing countries. The textile industry represents a vital sector for global economic growth, especially in terms of job creation, trade enhancement, and the generation of overall added value. However, the fast-paced evolution of fashion trends, combined with global population growth and rising living standards, has intensified the environmental impact of the textile sector. Among the most frequently cited concerns are the intensive consumption of natural resources, the generation of vast quantities of waste, and substantial greenhouse gas emissions. These opportunities and challenges have positioned the textile industry as a focal point in both academic literature and developmental strategies, identifying it as a sector with substantial potential for transitioning towards sustainable, circular, and innovative production, consumption, and business models. The primary aim of this paper is to highlight the key strategic directions that have shaped the development of the textile industry over the past decade. By applying relevant indicators, the study analyses the effectiveness of the green*

transition in the textile industry across EU countries and Serbia. The findings indicate the presence of certain similarities, as well as notable differences, between the countries examined. Furthermore, the paper identifies the key barriers impeding the adoption of sustainable innovations in the textile sector. Overcoming these challenges is essential for ensuring the continued implementation of reforms aimed at further "greening" the industry enhancing its sustainability and generating not only economic, but also social and environmental value.

Keywords: *textile industry, sustainability, transition, EU, Serbia.*

DRUŠTVENO-EKONOMSKI ASPEKTI SAVREMENIH TRENDOVA U RAZVOJU TEKSTILNE INDUSTRIJE

APSTRAKT: *Intenzivan tehničko-tehnološki progres poslednjih decenija uticao je na promenu uslova privređivanja u svim sferama poslovanja i života. Dati uticaj u mnogim oblastima delatnosti bio je veoma pozitivan i doprinosio je unapređenju poslovanja i poboljšanju uslova života. Međutim, vremenom su došle do izražaja i mnogobrojne negativne posledice ubrzanog rasta i razvoja i stalne težnje za sve većim profitom. Date negativne posledice tiču se, pre svega, narušavanja životne sredine, gomilanja otpada, preteranog iscrpljivanja prirodnih resursa, pada kvaliteta života i sl. Čovečanstvo je postalo svesno da ako se nastavi ovakav trend može doći do ugrožavanja ne samo budućeg rasta i razvoja, već i opstanka čovečanstva. Usled toga dolazi do formulisanja novih razvojnih modela i strategija koje bi trebalo da obezbede dugoročan održivi razvoj celokupne ljudske zajednice. Predmet ovoga rada je teorijski prikaz novih održivih razvojnih koncepata i analiza glavnih trendova u pogledu sprovođenja tranzicije tekstilne industrije razvijenih ekonomija i zemalja u razvoju. Tekstilna industrija predstavlja granu privrede koja je značajna za ekonomski rast zemalja širom sveta, naročito u pogledu doprinosa otvaranju novih radnih mesta, unapređenja trgovine i ukupne dodate vrednosti. Brza promena modnih trendova i rast svetske populacije i životnog standarda uticali su na povećanje negativnog uticaja tekstilne industrije na životnu sredinu, među kojima se najčešće ističu intenzivna upotreba prirodnih resursa, stvaranje velike količine otpada i emisija gasova sa efektom staklene bašte. Navedene pozitivne odlike i slabosti uticale su da upravo ova privredna grana bude prepoznata u literaturi i u razvojnim strategijama kao sektor koji ima široke mogućnosti za tranziciju ka održivoj, cirkularnoj i inovativnoj proizvodnji, potrošnji i poslovnim modelima. Cilj rada je da ukaže na ključne strateške pravce razvoja tekstilne industrije tokom poslednje decenije. U radu, primenom odgovorajućih pokazatelja, izvršena je analiza uspešnosti zelene tranzicije tekstilne industrije u zemljama EU i Srbiji. Rezultati analize ukazuju na postojanje određenih sličnosti, ali i značajnih razlika između posmatranih zemalja. Takođe, u radu je ukazano i na prepreke koje prate primenu održivih inovacija u tekstilnoj industriji, a čije prevazilaženje je važno za nastavak sprovođenja reformi u pravcu njenog daljeg „ozelenjavanja“, odnosno unapređenja njene održivosti i stvaranja ne samo ekonomske, već i društvene i ekološke vrednosti.*

Ključne reči: *tekstilna industrija, održivost, tranzicija, EU, Srbija.*

1. INTRODUCTION

The textile industry represents a very significant sector of the economy seeing that it contributes to the employment growth, trade advancement, added value increase as well as the overall growth and development of national economies. However, this industry is accompanied by many negative consequences which are, among others, the result of quick changes in fashion trends, the population growth and the increase in the standard of living. The adverse effect of the textile industry is visible first and foremost in the domain of the environment and is produced by overexploitation of natural resources, generating large amounts of waste, using harmful chemicals and greenhouse gas emissions. The mentioned strengths and weaknesses have contributed to this particular industry sector being recognized in literature and development strategies as one having a large potential for transition towards sustainable, circular and innovative production, consumption and business models. The aim of this paper is to emphasize the key strategic directions for the development of the textile industry that have been implemented over the past decade, as well as to analyze relevant indicators of the success of the green transition in the textile industry in the EU countries and in Serbia. The paper will also address the challenges that are encountered when applying the concept of sustainable development and innovations in the textile industry, as well as the need for overcoming these difficulties in order to successfully continue reforms aimed at further “greening”, i.e., improving the sustainability of the textile industry by creating not only economic, but social and ecological value as well.

2. CONTEMPORARY TRENDS IN THE TEXTILE INDUSTRY

The linear economy, which until recently dominated business and long-term economic development, has led to numerous, important and far-reaching negative consequences, primarily in the domain of the environment, but also in the broader socio-economic area. The constant pursuit of maximum profit and better competitive position has resulted in the excessive consumption of natural resources and energy, as well as the quick accumulation of large amounts of waste. Enormous environmental pollution, particularly the faster depletion of natural resources than their capacity for renewal, has caused severe ecological load, as well as a decline in the quality of life. Humanity has found itself at a turning point in its survival and development which requires a fundamental change in the philosophy that will guide the future development.

In these circumstances, the concept of sustainable development has emerged as a new developmental philosophy. The main elements of this concept are the green economy, circular economy and bioeconomy. The concept of *the green economy* represents an economic process characterized by low carbon emissions, highly efficient use of resources, as well as the pursuit of optimal achievement of social goals along with the minimization

of ecological risks. There are five key courses of action within the green economy that can be identified: achieving social well-being, attaining equity in the fields of social and human rights, recognizing the limits of natural resources and protecting them, using resources in more efficient ways and applying appropriate governance processes in the socio-economic sphere [1]. In this regard, the green economy can be viewed as one of the main instruments for future sustainable development. The advantages of applying the green economy concept include the following: improved human well-being, the achievement of social equality, reduction of poverty, minimization of harmful environmental impacts, reduction of carbon emissions, prevention of pollution, a shift toward the use of renewable resources wherever possible, creation of green jobs, prevention of biodiversity loss and effective waste management.

The circular economy, as an element of sustainable development, represents an economy whose aim is to ensure that products, components and materials retain their highest possible utility and value at all times throughout the economic process [2]. It is especially important to emphasize that one of the most significant conditions for realizing long-term sustainability, in addition to the establishment of a closed-loop system, is the long-lasting, fundamental transformation of lifestyles, value systems and consumption patterns.

The United Nations' Agenda for Sustainable Development adopted for the period up to 2030 defines seventeen sustainable development goals. The implementation of the concept of the circular economy supports eight of them: responsible consumption and production, clean water and sanitary conditions, decent work and economic growth, industry, innovation and infrastructure, sustainable cities and communities, climate preservation, marine conservation and the preservation of life on land [3].

In comparison with the linear economic model, the advantage of the circular economy is that it ensures the circular flow of matter and energy. Designing production and consumption in this way could provide long-term sustainability by applying clean technologies, developing a new approach to product design that facilitates efficient reuse, as well as the application of responsible management of natural resources and energy, with a focus on renewable resources and minimal generation of waste. In this regard, it would be possible to achieve the most important goals of the circular economy – restoration of natural resources, retention of resources in use, as well as the extension of product life cycles through appropriate design that prevents products from becoming waste and allows them to continue to be used, consequently reducing environmental pollution [4].

The concept of sustainable development is based on the efforts to reconcile economic, ecological and social demands while realizing socio-economic development. The green economy, circular economy and bioeconomy play particularly important roles in the realization of the abovementioned concept, along with other elements of sustainable development that should not be disregarded [1, 5, 6]. The application of the principles of sustainable development is of particular importance for economic sectors that are the largest polluters of the environment such as: the food industry, transportation, construction and the textile industry. So, the textile industry is officially found among the sectors that are the biggest polluters of the environment. The development of the textile industry so far has been predominantly based on the principles of the linear economy, which relies on the "take–make–use–dispose" approach. Frequent changes in fashion styles, the global

population growth and the increase in the standard of living have significantly contributed to the negative environmental impact of the textile industry, which means that applying the linear model in this sector would be unsustainable in the long run.

The current linear model of textile and clothing production and consumption encourages a fast fashion culture: more lower-quality clothing, shorter delivery deadlines, more frequent production lines and collections, a growing global population and expanding middle class, declining clothing prices (compared to prices of other consumer goods), increased demand for clothing and the growth in the consumption of clothing items.

The textile industry is an economic sector in which the principles of the circular economy could be applied very successfully. Namely, seeing that the textile industry uses natural resources, particularly water and energy, very intensively and often inefficiently in the production process, and considering the fact that this sector generates large amounts of waste that are poorly managed, emits greenhouse gases and uses chemicals, microplastics and microfibers intensively, the potential for implementing a sustainable and circular development model is very high. Implementing a new economic model in the textile industry is justified and desirable because it can help solve numerous problems, primarily those related to environmental degradation. In this way, the application of the circular economy can contribute significantly to improving the efficiency of resource use, increasing business profitability, as well as reducing the negative environmental impact, consequently enhancing the overall quality of life on Earth.

In order to successfully implement the circular economy in the textile industry, it is necessary to develop new business models. These models refer to clothing rental services, designing products in ways that enable reuse and recycling (circular fashion), encouraging consumers to purchase higher-quality clothing that lasts longer (slow fashion) and, more broadly, guiding consumer behavior toward more sustainable choices (e.g. second-hand shopping, fashion library, keeping clothes longer in use). The development of a circular business model in the fashion industry is compatible with Sustainable Development Goal 12, which promotes sustainable production and consumption for both producers and consumers, as well as with Sustainable Development Goal 11, which focuses on the development of sustainable communities through Goal 9 (industrial and technological innovation). Therefore, it could also lead to the achievement of decent work and economic growth, in line with Development Goal 8, and all of this would ultimately contribute to further improvements in environmental protection (Sustainable Development Goal 13) [3].

For many years, the textile industry has been faced with challenges such as the intensive use of natural resources, the generation of large amounts of waste, inefficient energy consumption, greenhouse gas emissions, environmental degradation etc. Solving these problems requires continuous promotion and adoption of the idea of incorporating circularity into the operations of this sector. The transformation of the textile industry toward circularity would enable the long-term sustainability of its operations. This way, it would be possible to produce high-quality products while preserving their value and durability, as well as to implement material circulation processes based on the principle of “product–waste–product.”

One of the advantages of the transition of the textile industry to a circular economy lies in the fact that such a business model would contribute to reducing waste generation primarily through the reuse and recycling of materials and textile products. Consequently, the main goals of implementing the circular economy in the textile industry would be the following: increasing product durability, ensuring “circular design”, enabling the reuse and repair of existing textile products, reducing and eliminating the use of hazardous chemicals in production processes, using raw materials and energy sources more efficiently, increasing the recycled content in products, applying new technologies for production and recycling, reducing carbon emissions and improving environmental quality.

The literature that analyses sustainable transformation in the fashion industry has presented a conceptual framework that illustrates the transition from conventional to sustainable fashion. The given model is based on a comprehensive understanding of the ecological, social and economic challenges the fashion industry is facing [7, 8, 9]. The model of sustainable transition in the fashion industry emphasizes the importance and necessity of improving the environment, social progress, economic sustainability, ethical consumer behavior and principles of circular economy, which represent the key elements for starting the transformation within the fashion industry. The main components of the model are the following:

- *Input* – made up of conventional fashion, which is the result of the current state of the industry, and which is most often characterized by mass production, a huge negative impact on the environment and poor working conditions.
- *Process* – made up of the five key components: environmental improvement, social progress, economic profitability, ethical consumer behavior and circular economy principles.
- *Result* – sustainable fashion which represents a direct result of applying the mentioned improvements, which results in the products which are ecologically acceptable and ethically made.
- *Continuous improvement* – ensures that the transformation is maintained and continuously improved, and must be continuous through monitoring, evaluation, regulation, education and transparency.
- *Outcome* – sustainable transformation of the fashion industry, which promotes responsible management of resources, represents the long-term outcome of this model.

So as to apply circularity as a basic business principle, it is necessary to insist on the constant reduction and elimination of waste in the production process, which would also lead to the reduction of environmental pollution. This process requires replacing synthetic materials, chemicals, microfibers, microplastics etc. (the use of which significantly affects environmental pollution) with biological materials characterized by non-toxicity and the possibility of returning to the biosphere. This group of materials includes, for example, bioplastics, biosynthetic fibers, biomaterials such as biopolyester, biological silk etc. On the other hand, applying new technological solutions in the process of efficient sorting and recycling can also lead to reducing the use of non-renewable resources and eliminating the negative ecological effects of the textile industry. Some of the main obstacles to the optimization of textile recycling are the following [10]:

1) Economic cost-effectiveness: From the perspective of the economic justification of recycling in the textile industry, it should be mentioned that many types of recycled textile waste are not suitable for multiple recirculation and use, as well as that the prices of some recycled textile fibers are relatively high, which is a consequence of the high costs of the recycling process.
2) The composition of textile products, because basic components of many textile products make them unsuitable for recycling.
3) Unavailability of recyclable textile materials – the amount of textile waste which is suitable and available for recycling is extremely insufficient.
4) Technological limitations – lack of technologies for sorting textile waste in preparation for recycling and technologies for recycling different types of fibers.
5) Lack of information and limited public participation – knowledge barrier (not knowing what to recycle) and attitude barrier (lack of commitment to recycling ideals).
6) Poor coordination, inadequate policies and standards.

Textile waste can generally be divided into three main types according to the source of origin: post-industrial waste (by-product of clothing production), pre-consumer waste (clothing of lower quality at the place of production or in the distribution retail center, unsold goods in the retail center) and post-consumer waste generated by consumers themselves (damaged, worn or unwanted clothes) [11].

The most significant factors for improving the recycling sector are the following: *designing textile products* in such a way that the design of the product enables easy disassembly, the possibility of recycling and the use of as few different materials as possible; *the infrastructure* that enables efficient collection of discarded textiles; *the application of innovative technology* that enables efficient sorting of discarded waste; and *undertaking adequate activities* that can contribute to the growing demand for recycled textiles [5].

Applying the concept of circular economy in the textile industry would enable the creation of a completely new and different textile industry compared to the existing one, an industry which would produce high-quality, long-lasting and affordable clothing. The new textile industry would enable the preservation of the value of textile products during and after use, as well as the sale of textile products at prices which are formed in accordance with the real costs of production and which include social and environmental externalities. New technological processes that contribute to the preservation of the environment and the quality of water, air and soil would be applied in the production process, and a new “circular“ design of textile products would be developed. Ecologically acceptable clothing or fashion design, which are acceptable both from the perspective of environmental protection and the protection of the health of consumers who wear the clothes, as well as workers who participate in their production, are called Eco-fashion [12]. Eco design can also significantly reduce energy consumption. Ecological clothes are the clothes which are produced from eco-friendly and sustainable resources. The process of producing ecological clothing requires appropriate management of all its stages, from the creation of designs for the environment, the procurement of raw materials, to the production of clothes,

appropriate distribution, and up to the consideration of their reverse logistics and waste [13].

Due to numerous negative consequences which are the result of the textile industry business operations, developed countries are taking appropriate measures in order to improve the social and ecological sustainability of the textile industry. These measures point out the necessity of the transition of the textile industry sector towards sustainable and circular production, consumption and business models. It is estimated that in the near future the three innovative trends could affect the textile and clothing industry [14]:

1) digitization of products, their design, production, distribution and retail processes, as well as the interaction of consumers/end users, factories, workplaces and supply chains;
2) sustainability, circularity and efficiency of resources, processes and the entire business;
3) new business and consumer models based on the sharing of production resources and end products, servitization, pay-per-use or subscription models, all of which lead to a collaborative or sharing economy.

It is also emphasized that in the future it will be necessary to implement a holistic business model that covers the entire production process. The circular model is emerging as a new business model. The circular business model enables businesses to create value while simultaneously increasing the efficiency of resource use by extending product life span and closing material loops in the business process. The main courses of action of circular business models are the following:

- extending the life span and resistance of the product in order to increase its durability, reusability and prolong its life cycle. The significance of these aspirations is ever greater since fast-changing fashion trends and lower product quality affect the shortening of the life span of clothing;
- optimizing resource use in order to reduce and optimize water and energy consumption, reduce harmful gas emissions and water pollution by using safe chemicals and adequate biodegradable materials. Textile companies use large quantities of water, energy and chemicals in their operations. Consequently, by introducing the principle of circularity in business, they also introduce the approach named *Access-based business models* so as to simultaneously increase the use of products and reduce the use of new materials and the creation of textile waste.
- collecting and reusing, and
- recycling and using materials.

Young entrepreneurs and consumers can play a key role in the process of developing innovative business models in the textile industry. It is precisely green (or ecological) entrepreneurship that advocates for the design and implementation of business models whose application can reduce or prevent the negative impact of fast fashion on ecological and social sustainability by introducing various types of eco-innovations [15]. Circular entrepreneurship represents a form of sustainable entrepreneurship which aims to apply the principle of circularity in business in order to protect the population and the environment. Companies whose operations are based on circularity should significantly contribute to

solving ecological problems by creating new ecologically sustainable processes, products and services.

Applying the circular economy in the textile and clothing industry is made significantly more difficult by three types of obstacles: unfavorable waste disposal practices of consumers (behavior and education), unfavorable waste disposal practices and opportunities of producers (infrastructure and processes for waste collection), as well as inadequate sorting and recycling technologies. If developing countries invested more in infrastructure for recycling and repairing, it would increase their capacity for the mentioned activities.

There are also numerous limitations and challenges in the fashion industry supply chain. These are, first of all: poor management, insufficient legislative control, lack of digitization, qualified workforce, inadequate financing, low performance, inadequate use of materials and energy, inadequate waste management, inadequate quality of resources, lack of governmental support, market demand, resistance to changing the way of thinking, management support and short-term visions [16]. The challenges and obstacles in the implementation of the circular economy can be put into seven different areas: technological, financial-economic, organizational, supply chain, institutional, consumer and social-ecological [17, 18].

Implementing innovative and circular business models is a process whose application requires the appropriate investment of human, material and financial resources. In the domain of the textile industry, this process can slow down due to the limited financial resources needed to ensure investments in the construction of the necessary technical and technological systems, then due to the underdevelopment of the circular market, the low degree of replacement of textile products produced according to the linear model with circular textile products, insufficiently developed legal regulations, the lack of professional knowledge and skills of the workforce in the area of the circular economy, as well as due to the inadequate and insufficient application of digital technologies. Obstacles to the implementation of sustainability innovations in the textile industry can be internal (high investment costs and regular business costs, lack of awareness of the need to create sustainable innovations) and external (lack of financial support from public funding sources, underdevelopment of public-private partnerships, unstable macroeconomic conditions etc.) [15].

One of the prerequisites for removing the abovementioned barriers is constructing an adequate institutional framework and infrastructure. It is also necessary to define and apply appropriate measures in order to prevent the creation of waste, as well as ensure effective monitoring of the application of the circularity principles in the textile industry with a focus on four key areas: production and consumption, waste management, secondary raw materials and competitiveness and innovation. Even though the application of the principles of green economy is necessary and required, it is shown in practice that its realization is very often a tedious and long-lasting task. This is especially true for developing countries, which do not have enough of their own resources to realize the given process in an appropriate and efficient manner, which is also true for our national economy.

As a result, long-term strategic planning and directing activities and resources rationally purposefully are necessary in this area.

3. THE CHARACTERISTICS OF THE GREEN TRANSITION OF THE TEXTILE INDUSTRY IN THE EU COUNTRIES

Business operations according to the principles of the circular economy were first implemented by highly developed countries. In the EU countries, the textile industry is considered to be one of the most resource-intensive sectors which has a great potential for the transition to innovative, sustainable and circular production, consumption and business models. Applying the circular economy in the textile industry of the EU countries should lead to the improvement of the ecological performance of textile raw materials and materials, production, consumption, management of textile waste, as well as their reduction, recycling, processing and calculation of environmental impact [19].

The most significant documents which point out the importance of the green and digital transition for the competitiveness of the textile sector, as well as the specific activities and obligations which it entais are the following: the European Green Deal (2020), the Circular Economy Action Plan (2020), the New Industrial Strategy for Europe (2020), the EU Strategy for Sustainable and Circular Textile (2022) and Strategic Research and Innovation Agenda for Textiles of the Future Partnership (2024).

The European Commission has presented a new strategy for the production of textiles in order to increase their durability, repairability, reusability and recyclability, as well as to combat fast fashion and encourage innovation in this sector. Building a sustainable and circular textile industry is defined as a new strategic direction for the future development of the textile sector in the EU countries, which aims to create a greener, more competitive and more modern textile sector with greater resistance to sudden global changes. The aim of this strategy is to build a framework and vision of the transition of the textile sector which will enable the production and sales of textile products that will be long-lasting, recyclable and largely made of recycled fibers and without hazardous substances by 2030. It is also very important that these products are made respecting human rights and environmental protection rules. The textile strategy contains the plans of the European Commission for adopting new regulations whose implementation would contribute to greater sustainability of the textile sector, as one of the largest polluters, exploiters and generators of waste in the world. The European Green Agreement aims to make the economic growth of all sectors sustainable, climate neutral, energy and resource efficient.

In addition to increasing certain types of costs for its realization, the strategy of a sustainable and circular textile industry has numerous advantages such as: longer-term consumer benefits from high-quality affordable textile products, reducing the importance of fast fashion, increasing the availability of economically cost-effective services for reusing and repairing textile products. In such a new competitive, resilient and innovative textile sector, producers need to take responsibility for their products along the value chain, including responsibility when their products become waste. Textiles placed on the EU market will have to be durable, “repairable“, made mostly from recycled fibers and without

any hazardous substances. The Strategy for Sustainable and Circular Textiles of the EU defines six key measures for achieving the objectives set:

1) Introducing mandatory requirements for ecological design – which would enable the life span of textile products to be expanded, which would then significantly reduce their impact on the climate and the environment.
2) Reducing and eliminating the destruction of unsold or returned textile products, because the destruction of unsold or returned goods, including clothing, is a loss of both value and resources.
3) Fighting against microplastic pollution – because it is estimated that more than 50% of the fibers used in clothing are synthetic, mainly polyester, and that share is growing more and more.
4) Introducing information requirements and digital passports for products – containing clear, structured and accessible information about the ecological sustainability characteristics of products, should encourage textile companies and consumers to make better choices and improve communication between actors along the value chains, including producers and recyclers.
5) Green claims that textile products are truly sustainable – which should ensure that consumers are more accurately informed at the point of sale about the product's life expectancy, as well as the information relevant to product repair, including a repairability rating, whenever available.
6) Extended responsibility of producers and encouraging the reuse and recycling of textile waste – because there is a significant potential to reduce textile waste, as well as the possibility for it to continue to create value by encouraging its preparation for reuse and recycling.

A new holistic business model is presented in the literature whose application includes all the phases of the supply chain [16]. According to this model, the life span of the product can be extended through the use of alternative sources of raw materials, such as waste, thus returning to the first step in the production chain (procurement of raw materials) and ensuring the principle of strict circularity. In order to improve the existing products and processes, it is necessary to apply green operations that include production and regeneration, reverse logistics, network design and waste management [13]. The main goal of green production, which includes activities such as reduction and recycling, is to reduce the negative impact of products on the environment by using appropriate materials. Unlike green production, regeneration involves reuse and recovery of products/materials. The model emphasizes the importance of green distribution through the establishment of local stores and infrastructure that will ensure resource efficiency, while challenges must be identified to ensure sustainable production at the production stage. The key principles that should be observed when applying this model are the vision of circular eco-design, the development of a reliable environment through the provision of key metrics and the quantification of circularity, but also the transfer of knowledge to both employees and customers of the fashion industry. Advertising, rebranding and creating partnerships towards circular fashion are key, because this enables a smoother transition of the industry

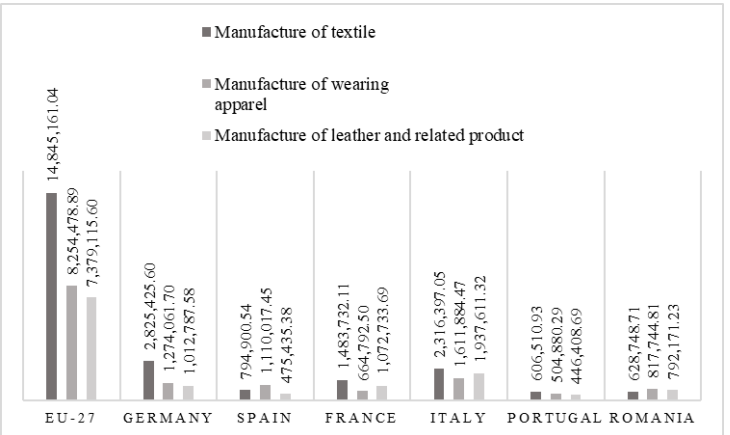
towards circularity, leaving no waste behind and is in accordance with the EU legislation and strategies.

However, applying business models based on the idea of reuse, repair, recycling and circularity in the EU textile industry sector has encountered numerous difficulties, such as increasing import and stronger competition from the third-world countries, the problems coming from rising energy costs, unsustainable use of primary raw materials, low business profitability, lack of appropriate skills, aging workforce, noise pollution, damaging human health etc. In addition to the abovementioned ones, other major problems are the following: the increased prevalence of counterfeit goods, the difficulties of small and medium-sized fashion enterprises in accessing financing, the general image of the sector as an industry with low profits, low level of innovation, low salaries and dubious working conditions, which have significantly reduced its attractiveness for young workers and experts, making the employment of qualified work force problematic [20].

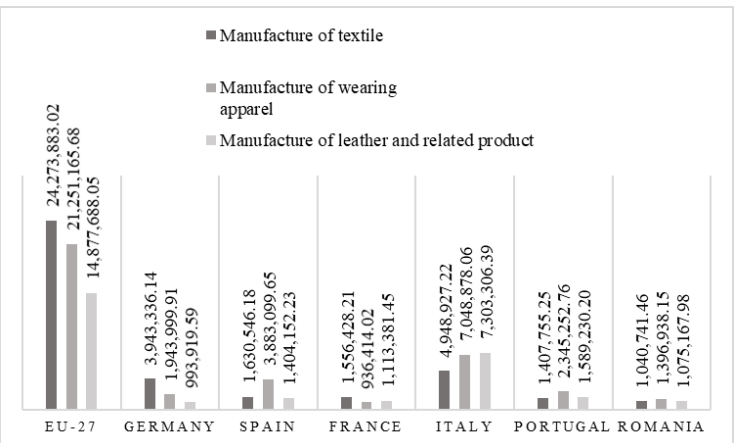
Applying the circular model means appropriate knowledge, experience and skills, as well as constant research and development work. So as to improve research and development and technological solutions for the circular and digital transition of the textile sector, it is necessary to: encourage innovation and research in the field of sustainable production processes and innovative technologies with low carbon emissions, provide support for the development of new digital technologies, support small and medium-sized enterprises and entrepreneurs in the textile sector to develop digital skills and to establish cooperation with the European Organizations for Standardization in order to adopt the necessary standards regarding innovative digital technologies which are significant for the textile sector.

The green transition of the textile industry also means providing the infrastructure for textile waste management (for collecting, sorting and processing of textile waste for reuse and recycling) and logistics. This requires building an infrastructure for collecting and sorting about 5 million tons of textile waste annually. The mentioned infrastructure should ensure a stable and reliable supply and use of high-quality secondary raw materials thanks to improved industrial capacities for recycled and renewable fibers and circular textile products.

The EU is one of the most significant participants in the foreign trade exchange of textiles, clothing, leather and similar products. In 2022, the EU exported the abovementioned products with a total value of about EUR 60 billion, while imports were about EUR 30 billion. The most important exporter and importer, with a share of 32% in total exports and 20% in total imports of textiles, clothing, leather and similar products in 2022 in the EU is Italy. Other than Italy, Germany, Spain, France, Portugal and Italy are important participants in foreign trade exchange (Figure 1).



(a)



(b)

Figure 1: International trade, imports (a) and exports (b) manufacturing of textile, wearing apparel and leather and related products in 2022 for EU-27, Germany, Spain, France, Italy, Portugal and Romania, thousand euro
Source: Author calculation based on Eurostat data

Digitization plays an important role in the sustainable development of the textile industry of the EU countries and it will be carried out using new technologies in order to enable effective monitoring of the transition of the textile industry from a linear to a circular business model: Artificial Intelligence (AI), Internet of Things - IoT, Big Data, 3D printing, Smart clothing, Digital Product Passport (DPP) etc.

Since human resources and human capital represent the most important elements of the company's capital, the realization of the circular economy means employees with

appropriate knowledge, experience, skills and competences. In the process of green transition, it is necessary to constantly invest in skills (also digital and circular) such as knowledge of circularity, processing, sorting and collecting of textiles. It is the staff who need to recognize textile waste as a resource on the market of secondary raw materials, as well as to determine how to further treat this resource and obtain a new value from it.

However, it is very unfavorable that only 13% of the employed workforce in the textile sector has high-level qualifications. This problem can be solved by permanently developing the skills that are necessary for the realization of the green and digital transition. These processes could increase the employment opportunities of highly qualified work force relatively poorly represented in the textile industry. On the one hand, the sector is struggling to attract qualified young talents, and on the other, business operations of small and medium-sized enterprises in the textile ecosystem are limited, among other things, by the lack of qualified workers. Within the EU Pact for Skills, the Commission supported the establishment of a large-scale skills partnership for the textile ecosystem to promote upskilling, reskilling and the acquisition and transfer of green and digital skills, including knowledge of life cycle assessment and value chain assessment. The goal is to increase opportunities for improvement, retraining and acquisition of new skills, which is especially important for the textile sector which represents a labor-intensive economic branch. The green transition itself, as a new business concept, implies the existence of a new professional workforce that possesses the appropriate knowledge and skills necessary for performing new jobs. The new professional profiles that are necessary are for example: circular design professionals, quality control operators, reverse logistics, waste management managers, digital designers, digital marketers, e-commerce experts etc. [1]. Consequently, the European Commission suggests constantly promoting and encouraging the improvement and adoption of existing and new green and digital skills.

4. COMPARATIVE ANALYSIS OF BUSINESS INDICATORS OF TEXTILE INDUSTRY IN THE EU AND RS

The contemporary textile industry is characterized by serious problems of unsustainable overproduction and overconsumption of the sector. Inefficient use of non-renewable resources, rapid change of fashion trends (wearing clothes several times and then throwing them away), a growing demand for lower quality clothing at a lower price, increasing production to respond to the latest fashion trends have all significantly led to the problem of unsustainability in this industry [21]. Today, clothes are made for a relatively short use, while underused clothing items are thrown away. All of the above, together with falling costs, a growing demand and consumption generated excessive growth in clothing production, which was also triggered by the growth of the world population and the expansion of the middle class, as well as the increase of the standard of living [11]. Consequently, in the following period it can be expected that production of the textile industry will continue to grow and, as it is estimated, the given growth will reach about 4% per year until 2030 [19].

According to Eurostat, in 2022, the manufacture of textile, wearing apparel, leather and related products achieved added value in the amount of € 71,497 million, which represents

a 2.98% share of the value added in the total manufacturing in EU-27. Italy achieved the highest value added (€ 28,079 million), then Spain (€ 8,235 million) and Germany (€ 7,740 million). This industry also employed 1,917,200 workers and had a 6.37% share of the employment in the total manufacturing in EU-27 (Figure 2). Italy has the largest number of employees in this sector (464,700), then Romania (274,400) and Poland (202,200). More than 90% of the companies in this industry are small enterprises which have fewer than 50 employees and which create more than 60% of the total value added of the manufacture of textile, wearing apparel, leather and related products in EU-27.

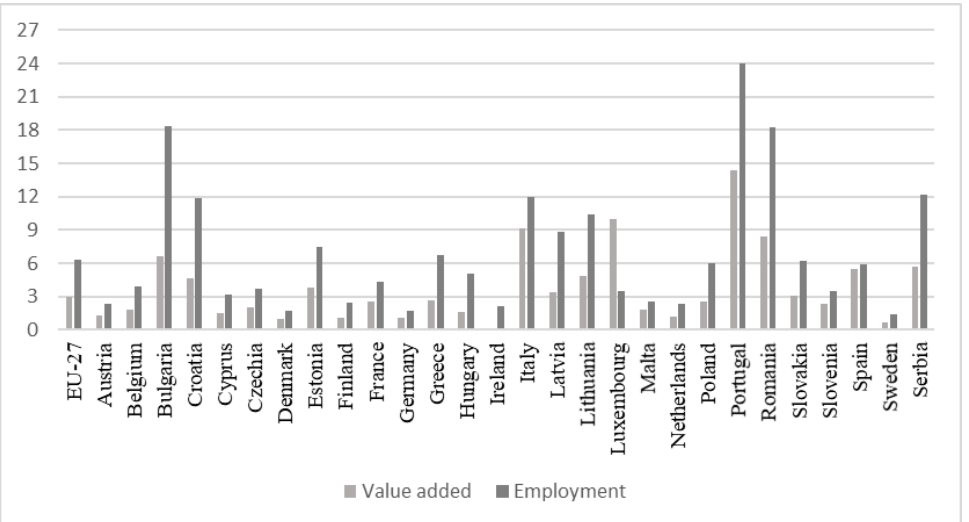


Figure 2: Value added and employment in the Manufacture of textile, wearing apparel, leather and related products in EU countries and Serbia in 2022, % of total manufacturing
Source: Author calculation based on Eurostat data

According to the data in Figure 2, it is evident that in Portugal the added value of the industry of textiles, clothing, leather and related products was 14.34% of total value added of manufacturing in 2022. Also, compared to the EU countries, Portugal recorded the highest participation of employees in the manufacture of textile, wearing apparel, leather and related products in total employment in manufacturing, which was 24.02%.
The analysis of the textile industry in Serbia leads to the conclusion that the added value of the textile, clothing, leather and related products in 2022 was 540 million euros, i.e. a 5.73% share of the value added in the total manufacturing in EU-27. This branch of industry employed 62,500 people, which represents a 12.17% share of the employment in the total manufacturing in Serbia. Such data also point to the fact that the productivity of the employees in the textile sector in Serbia is twice lower than in the EU countries. In recent years, a negative trend has been recorded in Serbia which shows a decline in the production of the textile and clothing industry (Table 1).

Table 1: Indices of total industrial production, manufacturing and textile sector in the Republic of Serbia, 2020-2022, previous year=100

	2020	2021	2022
Industry – total	100.6	106.3	101.7
Manufacturing	100.1	105.6	101.4
Manufacture of textile	97.0	95.9	95.4
Manufacture of wearing apparel	95.2	98.2	98.6
Manufacture of leather and related products	80.7	112.2	102.0

Source: [22]

We can conclude from Table 1 that in the given period Serbia experienced a decline in production in the textile and clothing industry, which was most evident in the production of textiles and was 4.1% in 2021 and 4.6% in 2022.

In recent years, the most significant ecological problems caused by the textile industry are connected, first of all, to the generation of waste, large consumption of water, energy and chemicals, as well as to the direct emission of CO_2. It is estimated that textile production is responsible for about 20% of global clean water pollution, which is caused by the use of chemicals for dyeing and final treatments. It is also estimated that the total level of fashion waste will rise to 148 million tons by 2030, which is 17.5 kg per year per capita worldwide [11]. It is devastating that only about 15% to 20% of textiles (depending on the region) are recycled, while the rest is disposed of in landfills or burned.

According to the Eurostat, the EU textile industry generated waste of 5 kg per capita in 2022 which represents an increase compared to 2012 (Table 2). Only four EU members, Belgium, Ireland, Luxembourg and Spain, have managed to reduce textile waste levels since 2012. The top seven producers of textile waste in the EU-27 in 2022 were: Belgium, Czechia, Luxembourg, Austria, Italy, the Netherlands and Portugal (Figure 3).

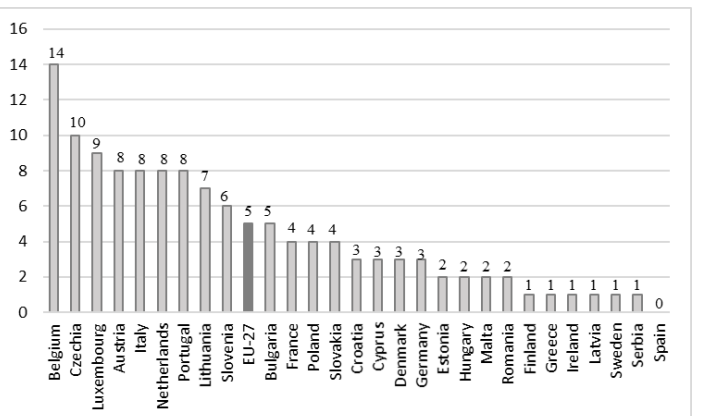


Figure 3: Textile wastes (all NACE activities plus households) in EU countries and Serbia from in 2022, kg per capita,
Source: Author calculation based on Eurostat data

Table 2: Change in textile wastes (all NACE activities plus households) in EU countries and Serbia from 2012 to 2022

Country	2012 (kg per capita)	2022 (kg per capita)	Change (%)
EU-27	4	5	25% ↑
Austria	5	8	60% ↑
Belgium	16	14	-13% ↓
Bulgaria	1	5	400% ↑
Croatia	1	3	200% ↑
Cyprus	1	3	200% ↑
Czechia	6	10	67% ↑
Denmark	3	3	0%
Estonia	1	2	100% ↑
Finland	3	1	-67% ↓
France	2	4	100% ↑
Germany	4	3	-25% ↑
Greece	0	1	↑
Hungary	2	2	0%
Ireland	5	1	-80% ↓
Italy	7	8	14% ↑
Latvia	0	1	↑
Lithuania	3	7	133% ↑
Luxembourg	11	9	-18% ↓
Malta	0	2	↑
Netherlands	7	8	14% ↑
Poland	2	4	100% ↑
Portugal	6	8	33% ↑
Romania	1	2	100% ↑
Slovakia	2	4	100% ↑
Slovenia	3	6	100% ↑
Spain	2	0	-100% ↓
Sweden	1	1	0%
Serbia	0	1	↑

Source: Author calculation based on Eurostat data

According to the data from the European Environment Agency, the purchase of textiles in the EU in 2020 generated around 270 kg of CO_2 emission per person. This means that textile products consumed in the EU generated greenhouse gas emission of 121 million tons [23]. The fashion industry, which is known for environmental degradation, social injustices and ethical issues, accounts for between 3 and 8% of global greenhouse gas emissions [24].

Table 3 shows emissions of pollutants (CO_2, CH4 and N_2O) in 2022 caused by the manufacture of textile, wearing apparel, leather and related products, as well as their change compared to 2012 for the EU countries and Serbia.

Table 3: Manufacture of textile, wearing apparel, leather and related products, change in air pollutants (CO_2, CH4 and N_2O) in EU countries and Serbia from 2012 to 2022

Country	CO_2, 2022 (tonne)	Change in CO_2, 2012-2022 (%)	CH4, 2022 (tonne)	Change in CH4, 2012-2022 (%)	N_2O, 2022 (tonne)	Change in N_2O, 2012-2022 (%)
EU-27	8,120,701.71	17%	4,861.81	-19%	165.08	31%
Austria	57,589	-48%	1.17	-62%	0.29	-63%
Belgium	156,217.69	-50%	13.25	-40%	0.85	-46%
Bulgaria	59,688.34	-27%	850.08	0%	0.87	-7%
Croatia	16,257.58	9%	0.47	-28%	6.47	-21%
Cyprus	1,116.12	-22%	0.07	-36%	0.03	0%
Czechia	80,911.54	-28%	6.69	-47%	0.83	-42%
Denmark	14,978.99	-41%	0.32	-93%	0.47	-29%
Estonia	6,276.76	-86%	2.83	-70%	0.49	-70%
Finland	8,027.7	-49%	0.15	-48%	0.19	-55%
France	576,550.28	-19%	26.73	-19%	8.42	65%
Germany	1,205,636.87	54%	239.83	244%	17.42	28%
Greece	2,094.05	-76%	0.19	-80%	0.07	-74%
Hungary	47,597.14	40%	1.28	8%	0.69	25%
Ireland	38,860.6	136%	1.95	122%	0.42	180%
Italy	4,204,669.61	66%	3,292.78	-22%	79.79	70%
Latvia	10,929.03	-61%	0.46	-53%	0.14	-48%
Lithuania	26,585.81	19%	9.72	-7%	2.91	-12%
Luxembourg	295	-99%	0.01	-99%	0.01	-89%
Malta	2,748.72	392%	0.05	67%	0	-100%
Netherlands	144,353.44	-31%	21.86	-13%	1.82	21%
Poland	173,898.86	9%	6.48	-22%	1.52	2%
Portugal	606,000	-24%	39.1	-1%	26.2	71%
Romania	137,541.87	-3%	13.29	-36%	2.7	-23%
Slovakia	61,406.72	16%	2.11	-27%	1.66	-21%
Slovenia	29,635.54	-24%	0.99	-74%	0.71	-7%
Spain	431,425.18	-28%	328.47	-47%	9.53	-36%
Sweden	19,409.28	-53%	1.49	-22%	0.57	12%
Serbia	56,465.81	-49%	142.13	37%	6.69	289%

Source: Author calculation based on Eurostat data

Based on the analysis of the data shown in Table 3, we can conclude that in 2022 the manufacture of textile, wearing apparel, leather and related products in the EU generated 8,120,701.71 tons of CO_2 emission, 4,861.81 tons of CH4 emission and 165.08 tons N_2O emission. The largest emissions were recorded in Italy and Germany, the countries with the most developed textile and clothing industry, which again points to the fact that the negative impact of this industry on the environment is still very large, but also to the necessity of intensifying the processes that lead to the sustainable development of this sector.

5. CONCLUSION

Intensive technical-technological progress in recent decades has significantly changed the economic conditions in all areas of business. In addition to considerable advantages, the development of technology has led to numerous negative consequences and the most significant ones are those connected to environmental pollution. Humanity is at a major turning point because it has been shown that this trend leads to endangering not only its future growth and development, but also its survival. So as to overcome these problems, new developmental models and strategies were formulated in order to ensure the long-term sustainable development of the entire human community. This paper focuses on the textile industry as a branch which, on the one hand, is of great importance for the economic growth of countries worldwide, and on the other in itself generates numerous, primarily ecological problems. Under such conditions, a fundamental change in the business model is necessary, a change which will make this industry sustainable in the long run. In this context, the textile industry has been recognized as a sector which has great potential for the application of a sustainable and circular model of business and development. The paper concludes that the application of the concept of circular economy in this industry would enable the creation of a completely new and different textile industry in comparison with the existing one, which would produce high-quality, long-lasting and affordable clothing and which would preserve the value of textile products during and after use and also enable the sale of textile products at realistic prices. Sustainable innovations, whose application would lead to the production of safer, more efficient, healthier and more environmentally friendly products, play an important role in the new developmental model of the textile industry. Young entrepreneurs and consumers can play a key role in the process of developing and applying innovative business models in the textile industry because green (or ecological) entrepreneurship advocates for the design and implementation of business models whose application can reduce or prevent the negative impact of fast fashion on ecological and social sustainability by introducing various types of eco-innovations.

Seeing that the implementation of innovative and circular business models is a relatively expensive process, its implementation first began in highly developed countries. Establishing a sustainable and circular textile industry has been defined as a new strategic direction for the future development of the textile sector in the EU countries with the aim of building such a framework and vision of the transition of the textile sector which will enable the production and sale of textile products which will be long-lasting, recyclable

and which will be largely made of recycled fibers and without hazardous substances by 2030.

The paper emphasizes that in the future we can expect the growth in the production of the textile industry to continue, and, according to estimates, the given growth will be about 4% annually by 2030. In Serbia, the value added in the industries of textiles, clothing, leather and related products in 2022 was 540 million euros, i.e. only a 5.73% share of the value added in the total manufacturing in EU-27. This branch of industry employed 62,500 people, which represents a 12.17% share of the employment in the total manufacturing in Serbia. Such data also point to the fact that the productivity of employees in the textile sector in Serbia is almost twice lower than the productivity in the EU countries. In recent years, there has been a decline in the production of the textile and clothing in Serbia. According to the data analyzed, we can conclude that in Portugal the added value of the industry of textiles, clothing, leather and related products was the highest with 14.34% of total value added of manufacturing in 2022. Also, in comparison with the EU countries, Portugal recorded the highest participation of employees in the manufacture of textile, wearing apparel, leather and related products in total employment in manufacturing, which was 24.02%. The data analyzed also show that the countries with the most developed textile industry (Italy and Germany) still have the highest emissions of harmful gases into the atmosphere. The realization of the green transition of the textile industry also means providing infrastructure for textile waste management, as well as the digitalization of the European textile industry in order to effectively monitor the transition of the textile industry from a linear to a circular business model.

ACKNOWLEDGEMENTS

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TRANSFORMATION OF TEXTILE PRODUCTION THROUGH INDUSTRY 4.0 IMPLEMENTATION: THE ROLE OF NEXT - GENERATION ROBOTICS

Original scientific paper
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ABSTRACT: *Industry 4.0 represents a new chapter in the development of manufacturing systems, where digitalization, automation, and the application of advanced technologies become key drivers of competitiveness. The textile industry, traditionally characterized by manual processes, is undergoing a profound transformation through the integration of next-generation robotics. This paper analyzes the significance and impact of robotic implementation within the Industry 4.0 framework on process efficiency, flexibility, and sustainability in textile production. Special attention is given to the application of collaborative and autonomous robots, which enable smart work organization, optimized transport and storage, and adaptive production flow management. The study highlights both the benefits brought by the adoption of advanced robotic systems and the challenges encountered during their implementation, such as the need for digital competencies among the workforce and high investment costs. Through the analysis of current trends and examples of good practice, the paper points to key development directions aimed at enhancing innovation, sustainability, and global competitiveness of the textile sector. The conclusion emphasizes the necessity of a strategic approach and continuous investment in new technologies to ensure a successful transition toward the smart factory of the future.*

Keywords: *Industry 4.0, textile production, next-generation robotics, automation, smart factory, innovation.*

TRANSFORMACIJA TEKSTILNE PROIZVODNJE KROZ IMPLEMENTACIJU INDUSTRIJE 4.0: ULOGA ROBOTIKE SLJEDEĆE GENERACIJE

APSTRAKT: *Implementacija industrijskih i servisnih robota u tekstilnoj industriji*

predstavlja ključni korak ka modernizaciji proizvodnje u skladu s principima Industrije 4.0. Analizom koristi i izazova, jasno je da primjena robotske tehnologije doprinosi većoj produktivnosti, standardizaciji kvaliteta, smanjenju grešaka te poboljšanju sigurnosti na radu. Iako su izazovi prisutni, posebno u vidu visokih početnih ulaganja, potrebe za obukom kadrova i tehničke integracije sa postojećim sistemima, dugoročne koristi opravdavaju ove napore. Posebno je važno istaknuti rastući značaj servisnih robota u logistici i inspekciji, kao i pojavu robotike nove generacije koja omogućava saradnju s ljudima, autonomno donošenje odluka i fleksibilnu reakciju na promjene u proizvodnom procesu. Uspješne implementacije u praksi pokazuju da tekstilne kompanije koje ulažu u automatizaciju postaju konkurentnije, brže se prilagođavaju tržišnim promjenama i bolje odgovaraju zahtjevima kupaca. Za dalji razvoj sektora, preporučuje se veće strateško ulaganje u integraciju robotike sa vještačkom inteligencijom i IoT tehnologijama, kao i poticaji za obrazovanje i prekvalifikaciju radne snage. Na taj način, tekstilna industrija može postići veću održivost, prilagodljivost i tehnološki napredak u godinama koje dolaze.

Ključne reči: *Industrija 4.0, proizvodnja tekstila, robotika sljedeće generacije, automatizacija, pametna tvornica, inovacija.*

1. INTRODUCTION

The textile industry, one of the oldest and most significant industrial sectors, is increasingly facing challenges in today's global environment. Traditional production models, largely based on manual labor and limited automation, are struggling to meet market demands that emphasize rapid adaptability, product customization, and sustainable operations [1-3]. Moreover, stricter requirements concerning environmental sustainability and energy efficiency further intensify the pressure on textile companies to redefine their manufacturing processes. In this context, the concept of Industry 4.0 represents a revolutionary trajectory for the transformation of manufacturing systems. Industry 4.0 encompasses the integration of digital technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), robotics, Virtual and Augmented Reality (VR/AR), and Big Data analytics into all aspects of production [4]. This transformation seeks to create intelligent production environments where humans and machines interact in real time to support flexible operations, efficient resource use, and tailored product output. Within this framework, *next-generation robotics* plays a crucial role. Unlike traditional industrial robots, typically confined to safety cages performing repetitive tasks, modern robotic systems are characterized by high autonomy, cognitive capabilities, and the ability to collaborate safely with human workers . Cobots and mobile autonomous robots contribute to enhanced flexibility and safety in manufacturing workflows, aligning well with the changing requirements of textile production. Beyond physical automation, next-generation robotics also introduces digital connectivity, providing the capability to collect, process, and analyze data in real time, which facilitates enhanced decision-making and predictive maintenance . These features position robotics as an indispensable element of Industry 4.0 implementation in the textile sector, where rapid adjustments to changing production

requirements and consumer expectations are increasingly critical. However, despite the evident benefits, the digital transformation of textile companies faces several challenges, including high initial investment costs, the need for comprehensive workforce training, and difficulties in integrating new systems with existing infrastructure [5, 6]. Moreover, adapting organizational culture and managing change are essential components for a successful transition. This study aims to examine the role of advanced robotic technologies in reshaping textile manufacturing within the framework of Industry 4.0. The focus is on analyzing the benefits and challenges associated with the deployment of collaborative and mobile robots in textile manufacturing processes, as well as identifying best practices for successful digital transition. Through a systematic review of the current literature and analysis of practical examples, this study aims to provide a comprehensive overview of emerging trends and development prospects in the digitalization of the textile industry. Previous research highlights that the adoption of Industry 4.0 not only boosts productivity in the textile sector but also supports sustainability and resilience in production systems [7]. The integration of robots with IoT devices and Big Data analytics enables dynamic production planning and monitoring, thereby increasing transparency and reducing resource consumption [8]. Additionally, the development of flexible robotic solutions is particularly critical for textile processes due to the diversity of materials and the complexity of fabric manipulation [9, 10]. Consequently, modern robotics is emerging as a core element of innovation strategies in the textile industry, laying the foundation for the creation of smart and sustainable production systems for the future.

2. INDUSTRY 4.0 AND THE TEXTILE INDUSTRY

Industry 4.0 represents a modern direction in industrial development, based on the integration of digital technologies, automation, and data management into manufacturing processes. By incorporating robotics, the Internet of Things, big data analytics, artificial intelligence, and advanced automation, this concept enables the development of 'smart factories' that operate with greater efficiency, adaptability, and responsiveness to market changes. The textile industry, traditionally known for its labor-intensive nature, is undergoing a rapid transformation through the implementation of Industry 4.0 principles, fundamentally redefining manufacturing, logistics, and market dynamics. Modern robotic systems enable precise, fast, and consistent execution of manufacturing tasks. In the context of the textile industry, robots are employed to automate processes such as fabric cutting, sewing, and product packaging, significantly reducing operational costs while increasing productivity [11, 12]. Internet of Things (IoT) technology connects physical devices via the internet, enabling continuous data collection and real-time processing. In textile production, IoT sensors monitor environmental conditions, machine status, and production flows, enabling rapid response to emerging issues and optimization of resource usage [13]. The figure illustrates the flow of smart manufacturing, starting with real-time data collection through sensors, followed by analysis using advanced algorithms and artificial intelligence. The gathered information enables process optimization through digital factories and cyber-physical systems, resulting in high flexibility and customized

production according to specific customer requirements. The integration of the Internet of Things (IoT), big data, and automated systems allows for rapid feedback and continuous improvement of manufacturing processes .

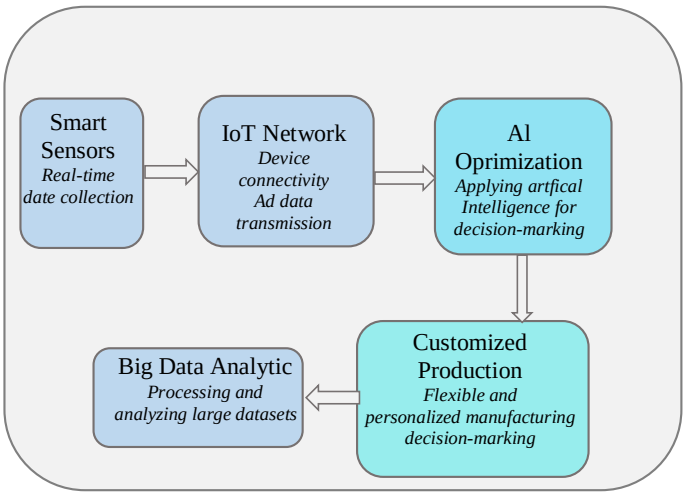

Figure 1: Flow of Smart Manufacturing: From Sensors to Customized Production

This structure supports more efficient, sustainable, and market-driven production. Smart sensors are crucial elements in the digitalization of manufacturing. They enable precise monitoring of parameters such as temperature, humidity, yarn tension, and machine conditions in real-time. Integrated with IoT networks, smart sensors provide vast amounts of data for advanced analytics, supporting predictive maintenance and production process optimization [14,15]. The importance of smart sensors in facilitating data-driven operations in the textile sector can be illustrated in the following Table 1. Table 1 highlights the critical role of smart sensors in enabling data-driven operations within the textile industry. It presents key functionalities such as real-time monitoring, quality control, and predictive maintenance, all of which contribute to increased efficiency and reduced downtime.
The table emphasizes how sensor integration supports automated decision-making and adaptive process management . These capabilities are essential for transitioning traditional textile production into a more intelligent and responsive manufacturing environment. Big data technologies enable the processing and analysis of massive volumes of data generated throughout the manufacturing process. In the textile industry, big data analytics is employed for demand forecasting, supply chain optimization, and product customization based on market trends [16]. The table emphasizes how sensor integration supports automated decision-making and adaptive process management . These capabilities are essential for transitioning traditional textile production into a more intelligent and responsive manufacturing environment. Big data technologies enable the processing and analysis of massive volumes of data generated throughout the manufacturing process. In

the textile industry, big data analytics is employed for demand forecasting, supply chain optimization, and product customization based on market trends [16].

Table 1: The importance of smart sensors in data collection in the textile industry

Component	Function	Benefits for the Textile Industry
Smart Sensors	Monitoring temperature, humidity, yarn tension	Reduction of defects, predictive maintenance
Internet of Things (IoT)	Network connection of sensors	Real-time monitoring, automatic responses
Big Data	Analysis of sensor-generated data	Production optimization, failure prediction
Artificial Intelligence	Automated decision-making and data analytics	Product personalization, efficient management

AI facilitates autonomous decision-making, predictive analytics, and process optimization without the need for constant human oversight. In the textile industry, AI is applied in quality inspection, product design, and predictive machine maintenance [17]. Advanced automation involves the use of software and hardware systems to perform production processes with minimal human intervention. Automated production lines accelerate manufacturing, minimize errors, and increase operational capacity in textile factories [18,19]. Smart factories in the textile sector are characterized by interconnected machines capable of self-diagnosis and autonomous corrective actions. Through the integration of IoT systems, predictive analytics, and adaptive automation, smart textile factories achieve high levels of flexibility and significantly reduce downtime [20]. The implementation of flexible automation and AI technologies allows textile companies to tailor products to individual customer preferences without significant increases in production costs. The mass customization concept enables rapid switching between different models, designs, and sizes [21]. Digitalization of supply chains enables full real-time visibility over inventory, manufacturing, and distribution activities. Through the use of technologies such as blockchain, IoT, and cloud computing, textile companies optimize logistics, reduce delivery times, and increase transparency [22].

3. INDUSTRIAL AND SERVICE ROBOTS IN THE TEXTILE INDUSTRY

3.1 Implementation of Robots and Service Robots in the Textile Industry

The textile industry, which has historically relied on manual labor, is undergoing a fundamental transformation driven by digitalization and automation. This evolution is driven by the need to address global competition, rising labor costs, and increasing demands for faster and higher-quality production. Central to this transformation are industrial and service robots [22, 24].

Although robotics has traditionally been primarily applied in the automotive and electronics industries, it has recently been making increasing inroads into the textile sector. The main motivations include efficiency improvement, quality standardization, and reduced dependence on manual labor [25]. Industrial robots are automated systems designed to perform tasks such as cutting, sewing, material handling, and product assembly with precision and repeatability. Their effectiveness is particularly notable in repetitive and high-precision operations, such as automated fabric cutting with robotically controlled blades or laser systems [26].

Robots are also used in textile finishing and the application of decorative elements, contributing to greater uniformity and reduced waste. In some Asian factories, fully automated production lines for manufacturing t-shirts and underwear already exist, operating with minimal human supervision [23].

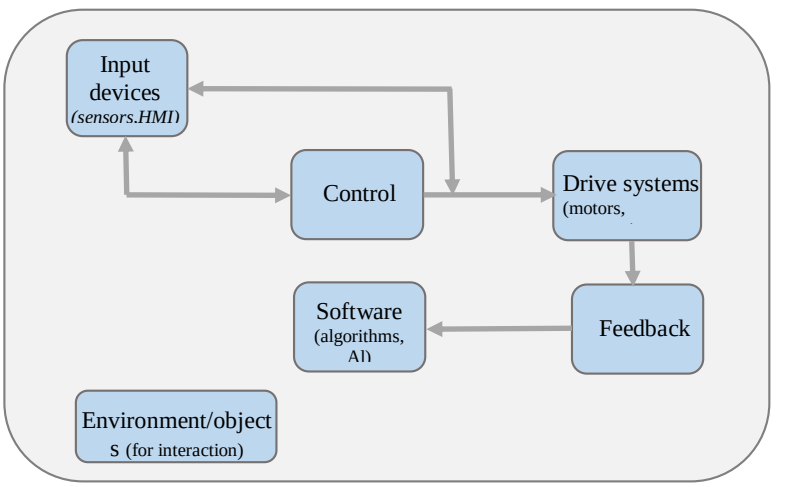

Figure 2: Diagram of Industrial and Service Robot Implementation

As shown in Figure 2, input devices include sensors (e.g., cameras, LIDAR, ultrasound, temperature sensors) and user interfaces (e.g., touchscreens or remote controls). The control unit—typically a central computer or microcontroller—manages system logic. Software includes path-planning algorithms, signal processing, and artificial intelligence (e.g., object recognition, navigation). The drive system consists of servomotors, actuators, and pneumatic components. Feedback loops provide sensor signals on command execution and system status (closed-loop control). The environment encompasses the physical space where robots operate, including objects being manipulated and users being served.

On the other hand, service robots in the textile industry perform supportive functions related to logistics, quality inspection, and material handling. Mobile logistics robots equipped with LIDAR sensors and cameras automate the transport of materials from warehouses to production lines, reducing downtime and increasing transfer efficiency [27].

Visual inspection robots use advanced sensors and AI to detect defects in weaving, dyeing, or printing processes, eliminating human error and improving final product quality [24,28]. According to available data, the number of installed robots in the textile industry has shown a steady upward trend over the past decade. Although precise yearly data are not always available, estimates based on industrial reports and automation trends indicate a consistent growth pattern [29].

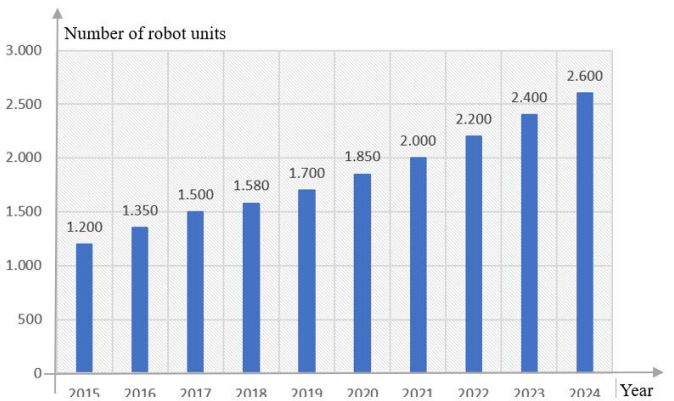

Figure 3: Annual Estimates of Robot Installations in the Textile Industry

This sustained growth reflects increasing acceptance of robotics in the textile industry, especially in Asian countries, where governments and industry leaders recognize automation as a strategic asset for maintaining global competitiveness. For example, China has significantly increased robot use in textile manufacturing as part of its "Made in China 2025" initiative aimed at modernizing industry through advanced technologies [33].
In addition to industrial robots, the textile industry increasingly relies on service robots to enhance both internal transport within production processes and logistics operations in storage facilities. These robots contribute significantly to streamlining material handling, ensuring greater operational efficiency, and reducing manual labor dependency in both manufacturing and warehousing environments [23, 25]. Global trends in the deployment of service robots for professional applications in 2023 are illustrated in Figure 4, which highlights seven key sectors of application [29,30]. As depicted in Figure 4, logistics and transport dominate the use of service robots, with approximately 113,000 units installed—accounting for nearly half of all professional service robot implementations. This prevalence reflects the growing demand for automation in warehousing, distribution, and delivery operations, which contributes to faster workflows and significant cost reductions [24,30]. The increasing integration of service robots into intralogistics systems aligns with broader trends in smart manufacturing and Industry 4.0 initiatives, where real-time data, mobility, and adaptive intelligence are essential [25, 32]. Integrating industrial and service robots enhances work organization and process scalability. Combined with Manufacturing

Execution Systems (MES) and the Internet of Things (IoT), robots become part of a broader smart factory ecosystem.

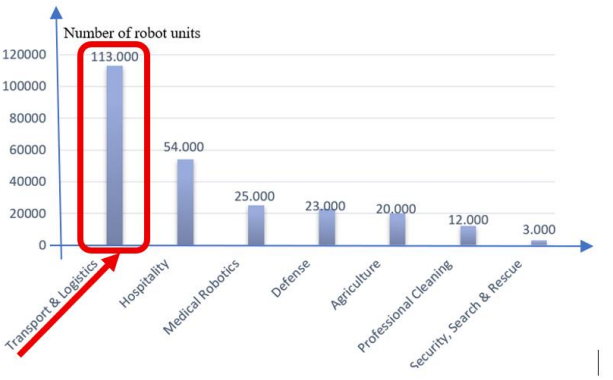

Figure 4: Deployment of service robots for professional use in seven leading sectors (2023)

For instance, when an automated inspection robot detects a defect, the system can adjust machine parameters in real time, forming a closed loop of control and self-adjustment [33]. In addition to technical benefits, robots also contribute to improved workplace safety by taking over hazardous tasks such as handling heavy loads, working with toxic materials (e.g., during dyeing), or operating in high-temperature environments. Despite high initial implementation costs, long-term benefits such as reduced labor needs, increased productivity, and higher precision justify the investment, particularly in countries with rising wages and stringent quality and sustainability regulations [30].

3.2 The Role of Next-Generation Robotics in Textile Manufacturing

Next-generation robotics represents an advanced form of automation that includes the ability to learn, make independent decisions, and collaborate safely with humans in real-world production environments. This concept encompasses three key categories:

- *Cognitive robots* that use machine learning and AI algorithms to adapt to complex tasks;
- *Collaborative robots (cobots)* that work alongside humans in shared workspaces;
- *Mobile robots* that navigate autonomously and optimize intralogistics.

Unlike traditional industrial robots, next-generation systems do not operate solely based on predefined tasks, but actively communicate with the environment and human operators [22,32]. In the textile industry—known for the complexity of handling flexible materials—such robotic systems offer numerous advantages. These robots enable adaptable production flows, as they can be quickly reconfigured to process different types of fabrics or clothing designs. They also exhibit high adaptability by responding to production changes without requiring hardware replacement. Collaboration between humans and robots contributes to

higher productivity and ergonomics, as robots take over strenuous, repetitive, or hazardous tasks, freeing workers for supervision and creative activities [34]. Moreover, these systems reduce labor costs and material waste through precise and predictive process control. Examples of successful application of this technology already exist. For instance, Sewbo Inc. has developed a robotic system for automatic sewing using fabrics that are temporarily secured, allowing for precise automation of previously difficult-to-automate production stages [32]. In Italy, collaborative robots assist in highly customized garment production, preparing components that human workers then finalize. Mobile robots in textile company logistics centers, such as those used in Zara and H&M warehouses, have improved internal distribution efficiency and reduced order processing time by more than 30% [30]. Finally, cognitive robotic systems can be applied for real-time defect detection during weaving or textile printing, analyzing visual data through deep learning algorithms. These systems not only improve product quality but also conserve resources by enabling early detection of flaws [28]. By implementing next-generation robotics, the textile industry is gradually shifting from a traditional mass-production model to a digitally oriented, adaptable, and sustainable production platform aligned with Industry 4.0 principles.

4. KEY BENEFITS AND CHALLENGES OF IMPLEMENTING ROBOTIC TECHNOLOGY IN THE TEXTILE INDUSTRY

The implementation of robotic technology in the textile industry is increasingly recognized as a strategic response to global competition, rising labor costs, and the demand for more efficient and flexible production systems. Although robotics offers a wide range of advantages, it also presents several implementation challenges that need to be addressed for long-term success and sustainability.

- ***Key Benefits***

One of the main advantages of using robots is increased productivity, as they can work continuously without the need for breaks or rest, ensuring high throughput and consistency across all production lines. This is particularly relevant in the textile sector, where high-speed and repetitive operations such as cutting, sewing, and material handling benefit significantly from automation [23].

Another major benefit is the reduction in production errors. Thanks to their precision and consistency, robots reduce the possibility of human error, thereby decreasing waste and improving product quality. Advanced vision systems and AI integration allow for real-time detection and correction of defects in fabric weaving, dyeing, or printing processes [24].

Robotics also improves workplace safety, as it is used in hazardous conditions where there is a risk to workers, such as working with toxic materials or high temperatures [32].

In addition, automation leads to shorter production cycles. The ability of robotic systems to quickly adapt to different tasks and types of materials enables a faster response to changes in market demand [22]. This flexibility aligns with the growing trend toward personalized and just-in-time manufacturing in the textile industry.

- ***Key Challenges***

Despite the benefits, several challenges hinder the widespread adoption of robotics in textile manufacturing. The first and most obvious challenge is the high initial investment cost in robotic systems. Acquiring and integrating robotic systems tailored to textile applications involves substantial capital expenditures, which may not be feasible for small and medium-sized enterprises [21]. A second significant challenge lies in the training and reskilling of the workforce. As robotic systems require technical know-how for operation, programming, and maintenance, companies must invest in continuous education and capacity building for their staff. The skills gap between traditional textile workers and modern automation needs is often substantial [31]. Another challenge lies in integrating modern robotic solutions into existing, often outdated, production systems. Many textile factories still rely on outdated equipment and infrastructure, making it technically and economically difficult to implement advanced robotics without extensive retrofitting or complete system overhauls [23]. Lastly, successful implementation also depends on organizational readiness and cultural transformation. The introduction of robotics requires a shift in managerial approach, as well as the organization's readiness to embrace innovation and technological change. Without these, even the most advanced systems may fail to deliver expected outcomes.

5. AN EXAMPLE OF A SUCCESSFUL IMPLEMENTATION OF ROBOTIC TECHNOLOGY IN A MEDIUM-SIZED TEXTILE COMPANY

The introduction of robotic technologies into textile production is not exclusively a privilege of large multinational companies. Medium-sized enterprises (SMEs) can also benefit significantly from automation when it is strategically planned and tailored to specific production needs. The following example illustrates a hypothetical yet realistic case of a medium-sized textile manufacturer that successfully implemented both an industrial and a service robot to modernize its operations.

- ***Case Example: "TexPro Ltd." – A Mid-Sized Apparel Manufacturer***

TexPro Ltd., a regional clothing manufacturer with around 250 employees, faced growing challenges caused by labor shortages, rising costs, and inconsistent product quality. To address these challenges, the management team initiated a phased robotic integration program focusing on automating high-precision tasks and improving intralogistics.

- ***Implementation Phases***
  - *Needs Assessment:* The first phase involved a detailed internal audit of production bottlenecks, error rates, and labor allocation. It was found that manual fabric cutting and internal material transport accounted for the majority of delays and inconsistencies.
  - *Robot Selection:* Based on the analysis, TexPro selected:
    - An industrial robotic manipulator with an integrated laser cutter, designed for precise fabric cutting.
    - A mobile autonomous robot (AMR) for internal logistics, designed to transport fabric rolls from the warehouse to the sewing stations.
  - *System Integration:* The industrial robot was integrated with a CAD/CAM system and programmed to cut up to 500 fabric pieces per hour with an error margin

below 0.5%. A mobile autonomous robot (AMR) was connected to the warehouse management system and used LiDAR technology and AI-based navigation to move safely through the production area.

- *Process Optimization* : After implementation, the production process was optimized through real-time data collection and machine learning algorithms. The material transfer time was reduced by 40% thanks to the AMR, while the robotic cutter increased processing capacity by 60% and almost completely eliminated cutting errors.

❖ ***Measurable Outcomes***

The integration of robotic technologies resulted in:

- A 25% overall increase in productivity.
- A 15% reduction in material waste.
- A 30% decrease in production cycle time.
- Improved worker safety by automating high-risk tasks.

These results demonstrate that even medium-sized companies can achieve significant benefits when robotic technologies are strategically and purposefully integrated into the production process[25].

❖ ***Supporting Industry Examples***

A comparable real-world example includes Sewbo Inc., which developed an automated sewing system using an industrial robot capable of handling chemically stiffened fabrics, previously considered too flexible for automation [32]. Similarly, H&M's logistics centers have implemented service robots for internal transport and order sorting, increasing delivery speed and reducing human error [31].

6. DISCUSSION

The application of robotic technologies in the textile industry brings numerous advantages that, in practice, often outweigh the existing challenges. Analysis of case studies and examples, including the case of a mid-sized company that successfully introduced automation, confirms that robotics contributes to increased efficiency, precision, and workplace safety, while simultaneously reducing operational costs and errors [23,25].

Practical outcomes demonstrate that the advantages of deploying both industrial and service robots are significant. Shortened production cycles, more consistent quality, and improved process control indicate that automation is becoming crucial for the competitiveness of modern textile manufacturing. Moreover, service robots used in warehouses and logistics improve delivery speed and reduce the need for manual labor in hazardous environments [31].

However, certain challenges still exist – primarily high initial costs, which are often beyond the capabilities of small and medium-sized enterprises and integrating new technologies with legacy systems requires technical expertise and time. Additionally, substantial investment in workforce training is necessary to fully realize the benefits of robotic technology [22].

Looking forward, there are numerous opportunities for further development. Notably, the integration of robotics with artificial intelligence (AI) enables robots to learn from data and make autonomous decisions in real time, moving beyond traditional automation toward *intelligent manufacturing systems* [22]. An additional perspective for development is the application of predictive analytics, which enables timely equipment maintenance and more precise production planning.

In conclusion, while implementation challenges remain, practical experiences show that a well-planned and phased introduction of robotic technologies significantly enhances performance in the textile sector. Given the rapid pace of technological advancement, it is expected that the integration of robotics, AI, and IoT will soon become standard practice rather than an exception.

7. CONCLUSION

The introduction of industrial and service robots represents a key step towards modernizing textile production in accordance with the principles of Industry 4.0. An analysis of the benefits and challenges clearly indicates that robotic technologies contribute significantly to increased productivity, standardized quality, error reduction, and improved workplace safety. Although there are still barriers such as high initial costs, the need for employee training, and technical integration with older systems, the long-term benefits outweigh these challenges. Notably, the growing importance of service robots in logistics and quality inspection, along with the emergence of next-generation robotics, enables human-robot collaboration, autonomous decision-making, and flexible adaptation to changing production conditions. Practical examples show that textile companies investing in automation gain a competitive edge, respond more quickly to market demands, and enhance customer satisfaction. For the continued advancement of the sector, strategic investment in integrating robotics with artificial intelligence and IoT technologies is strongly recommended, along with initiatives aimed at education and workforce reskilling. This will enable the textile industry to become more sustainable, adaptable, and technologically advanced in the future.

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TEAMWORK AS AN INFLUENTIAL FACTOR OF EMPLOYEES SATISFACTION WITH WORKING CONDITIONS IN TEXTILE INDUSTRY

Original scientific paper
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***APSTRACT**: Complex socio-technical systems of the textile industry require a special organizational structure of the occupational safety system, based on a systemic approach, the influence and mutual relationship of various factors and stakeholders. In this regard, the quality of the safety system in textile industry organizations largely depends on teamwork and the consistency of management in maintaining occupational safety as significant factors of human resource management and the occupational health and safety system itself. The research presented in this paper was conducted on a sample of 215 respondents employed in the textile production sector from Southeast Serbia. The software program SPSS 21.0, exploratory factor analysis (EFA) and structural equation modelling used for statistical data analysis. The results obtained indicated an exceptional connection between the analyzed factors that were identified as significant for the efficient improvement of the functioning of the occupational safety system in textile industry organizations. The methods applied in this paper can be successfully used to improve the work environment safety system in the production processes of the textile industry and the work processes in them.*

***Keywords:** occupational safety system, safety performance factors, textile industry.*

TIMSKI RAD KAO UTICAJNI FAKTOR ZADOVOLJSTVA ZAPOSLENIH USLOVIMA RADA U TEKSTILNOJ INDUSTRIJI

***APSTRAKT:** Složeni socio-tehnički sistemi tekstilne industrije zahtevaju posebnu organizacionu strukturu sistema bezbednosti na radu, baziranu na sistemskom pristupu, uticaju i međusobnom odnosu različitih faktora i zainteresovanih strana. S tim u vezi kvalitet sistema bezbednosti u organizacijama tekstilne industrije u mnogome zavisi od timskom rada i doslednosti menadžmenta u održavanju bezbednosti na radu kao značajnih faktora upravljanja ljudskim resursima i samog sistema bezbednosti i zdravlja na radu zaposlenih. Istraživanje prikazano u ovom radu sprovedeno je na uzorku od 215 ispitanika*

zaposlenih u sektoru proizvodnje tekstila iz Jugoistočne Srbije. Softverski program SPSS 21.0, eksplorativna faktorska analiza (EFA) i modeliranje strukturnih jednačina korišćeni za statističku analizu podataka. Dobijeni rezultati ukazali su na izuzetnu povezanost analiziranih faktora koji su identifikovani kao značajni za efikasno poboljšanje funkcionisanja sistema bezbednosti na radu u organizacijama tekstilne industrije. Metode primenjene u ovom radu mogu se uspešno koristiti u cilju unapređenja sistema bezbednosti radne sredine u proizvodnim procesima tekstilne industrije i radnih procesa u njima.

Ključne reči: *sistem bezbednosti, faktori bezbednosnih performansi, tekstilna industrija.*

1. INTRODUCTION

The textile industry is one of the largest and most complex sectors of industrial production. Every process of textile production, whether traditional or modern, to a greater or lesser extent requires the synchronization of work processes, teamwork and great responsibility of the management. Therefore, complex technical systems of industrial processes require a special organization of OSH systems, based on a systematic approach, interaction and interconnection of different elements and stakeholders [1]. Changes in the modern textile industry in recent years have not significantly affected the reduction of safety and health problems in this branch of industry [2]. What can be singled, in recent years, the activity of human resources management in preserving the safety and health of workers and the active participation of management in the promotion of health at work in this segment of industrial has increased significantly and thus the impact on the positive attitude of employees about working conditions. Consistency of management in maintaining occupational safety is a specific and critical component of safety climate, which refers to workers' perceptions of the degree to which their managers value and support safe work and are committed to worker safety. Theoretically, it should have a positive effect on teamwork in textile industry. According to the principles of social understanding, employees who perceive that their manager is concerned and committed to their physical safety at work will be significantly motivated to reciprocate and implement behaviors that support workplace safety [3–7]. Supporting team attitudes and behaviors resulting from social responsibility processes also contribute to positive interpersonal relationships in which teamwork can only develop positively. Conversely, employees may lack the motivation to engage in behaviors that support both teamwork and workplace safety. Furthermore, by promoting a clear priority of safety and the importance of employees, managers can work to remove some doubts that would allow a better shared understanding of the process and perceptions of effective teamwork. Based on the data collected through the literature review, the research methodology was developed. The steps contains the definition of research hypotheses, conceptual model, methodology and research flow, analysis of results and concluding observations with implications for future research.

2. METHODOLOGY

2.1. Sampling and data collection

The paper presents a survey conducted among employees who works in the production processes of the textile industry, in the area of Southeastern Serbia. The research included 215 respondents. Looking of the demographics of the sample, 77.18% of the total number of respondents is female gender and 22.82% are male. Between 30-50 years old where 91.56% of employees, while 8.44% of respondents have 20-30 years. In the research participants younger than 20 years where not included. The level of education of the employees presents that the majority of respondents (51.09%) have secondary school education, 29.10% have higher education with a university degree, 11.87% have higher education, while minority of respondents (7.94%) are low-skilled workers.

For the purpose of the research, a structured questionnaire model was used, and the research methodology for the collection of data on the attitudes of the employees was selected. The questionnaire contains 5 questions of demographic character, and 15 questions who explaining the aim of the research. A five-point Likert-type scale was used for assessment, and Cronbach's alpha coefficient was used for its validity and reliability. Quantitative data processing was performed using the SPSS 21.0 software program and structural modeling based on covariance and path analysis. Structural regression models are systems of linear equations [8–10]. It allows for the combination of structural equation and factor analysis. Factor analysis is a technique that deals with the measurement model. For the analysis of the mediating effect, the bootstrapping method was used with a confidence interval of 95% [11]. Based on the created questionnaire with formed groups of questions, the hypotheses were established related to consistency of management in maintaining occupational safety and teamwork as a influential human and organizational factors of employees satisfaction with working conditions.

2.2. Research hypotheses and the conceptual model

By actively promoting safety at work, management directly encourages open communication among employees about certain hazards and safety issues at work. This open dialogue occurs both among employees and among managers and can extend to other areas of teamwork, fostering a culture of information sharing and collaborative problem-solving. As a result, employees feel safe and supported by their employer and are more engaged and dedicated to their work tasks [15]. Management's consistency in maintaining occupational safety shows that the company values the well-being of its employees, building trust and fostering a stronger sense of teamwork. In this regard, a strong organizational safety culture leads to greater awareness of safety procedures and a reduction in workplace accidents through more efficient cooperation and teamwork at all levels. Employees' perceptions of management's positive attitudes and actions lead to a reduction in workplace injuries and better safety [16-17]. The success of creating safe working conditions depends on how much it is received as the responsibility of management and how it is integrated into the existing management system. Taking into account the above, the following hypothesis is tested:

Hypothesis H1: Management's consistency in maintaining occupational safety has a positive impact on teamwork

Management's consistency in maintaining occupational safety has a clear impact on improving employee satisfaction with working conditions. The mere understanding of

employees that the job prioritizes their safety at work creates a sense of being valued and safe, which leads to increased employee job satisfaction, which in turn positively impacts the productivity of the same organization. Numerous studies indicate a positive correlation between commitment to safety management and employee satisfaction, through safety programs, equipment, and resources [12–13]. Caring for the well-being of employees fosters a positive safety climate within the organization itself, and by prioritizing safety at work, it not only protects employees, but also creates a more positive and productive work environment [14]. Taking into account the above, the following hypothesis is tested:

Hypothesis H2: Management's consistency in maintaining occupational safety has a positive impact on employee satisfaction with working conditions

Despite the obvious importance of teamwork, this influential factor in workplace safety has been less studied in previous period. The literature on worker safety has so far focused mainly on safety climate, or workers' perceptions of the relative value of safety in the work environment, based on established policies, practices, and procedures [18]. In his research, Clarke points out that factors such as work group cohesion and peer support are much less studied in the safety literature when other job-related characteristics are taken into account, but are likely important for worker safety [19]. Some other analyses of worker safety have also only indirectly included teamwork [20]. Despite the relative lack of research, teamwork can be considered a specific critical variable to highlight in relation to worker safety, given its importance in textile organizations where, due to the complexity of production processes, this work environment factor can have a major impact on worker safety [21]. To all this, it should be added the fact that it can be influenced by team leaders to improve both work results and worker safety, and therefore represents a significant influential work environment factor. Following through, the next hypothesis is tested:

Hypothesis H3: **Teamwork has a positive impact on employee satisfaction with working conditions**

Numerous studies on occupational safety show that both individual and organizational factors, as well as teamwork in the organization, have a mediating role in the outcomes related to employee safety at work and their satisfaction with working conditions [22], which also affects the safety performance of the organization in general. For the reasons stated above, the research was set up with the assumption that teamwork will have a positive mediating role between management's consistency in maintaining occupational safety. Therefore, it is stated that a positive perception of safety leadership will be associated with a positive perception of safe working conditions, which in turn will be positively associated with employee satisfaction with working conditions [23]. Zohar finds that safety climate has a mediating role in the effect of transformational leadership on injuries at work [22]. Accordingly, the fourth research hypothesis was formulated:

Hypothesis H4: Teamwork has a partial mediating role in the relationship between management's consistency in maintaining occupational safety and employee satisfaction with working conditions

A conceptual model of positive impact is shown in Figure 1.

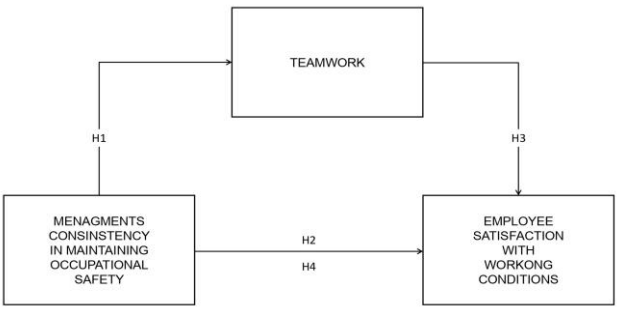


Figure 1: Conceptual model

3. RESULTS

The set of collected data was analyzed by Structural Equation Modeling (SEM) methodology and using the statistical tool software packages SPSS 21.0.

3.1. Descriptive statistics

Table 1 shows the results of the descriptive statistical analysis and the expressiveness of the research results. According to SPSS 21.0 variable values were calculated as the average values. The obtained results indicate the positive opinions of the respondents that the given parameters can significantly influence the influential factors as a measure of the development of the OSH climate, i.e. the obtained values of standard measure of central tendency were used - arithmetic mean (AS) and measure of variability - standard deviation (SD), which are above average considering the theoretical range of the scale (1-5).

Table 1: Expressiveness of the research results

Main hypothesis of the research	MIN	MAX	AS	SD
H1	1	5	4.25	0.572
H2	2	5	4.83	0.705
H3	2	5	4.75	0.562

3.2. The reliability analysis of the safety indicators

Statistical data processing requires the determination of the validity and reliability of the measuring scale as a starting point, i.e. of the results obtained on the basis of the collected and processed data [7]. For this purpose, the assessment of internal consistency of the instrument for data collection was carried out using Cronbach alpha test [24-25]. Cronbach's formula is used to calculate the average values of the correlation between items of the measuring instrument when the answers to questions are rated on the basis of the degree of the given threshold (the Likert's five-point scale).

Table 2: Reliability of the entire measurement scale

Main hypothesis of the research	Number of items	Cronbach's Alpha
H1	5	0,892
H2	5	0,910
H3	5	0,804
Reliability of the entire measurement scale		α=0.869

The values obtained based on the reliability test of each subscale, shown in Table 2, indicate an acceptable to high level of reliability, i.e. the obtained value α=0.869 indicates a high level of reliability of the used measurement scale, and the statements in the questionnaire show a high level of agreement. According to this a good possibility of modeling results of the questionnaire based on the considered population.

3.3. Control model

In order to apply factor analysis, testing the adequacy of the sampling was performed (MSAs - Measures of adequacy sampling) using a KMO (Kaiser-Meyer-Olkin Measure of Sampling Adequace) test and Bartlett test of sphericity (Bartlett's Test of Sphericity). Based on the literature, the minimum acceptable value for KMO indicator is 0.6, while the level of significance of the Bartlett's test is $p \leq 0.05$. The obtained result of the KMO coefficient is 0.849, which indicates that the collected data are suitable for the application of the factor analysis. As well, the Bartlett test of sphericity shows significance (p=0.000), indicating that there are correlations among the items within the measurement instrument, that is, that the correlation matrix is not an identity [7, 24]. The next steps of the study examine the correlation between the 15 items of the questionnaire (variables) and safety in production companies. The factor loadings of the variables range from 0.433 to 0.869, which is above the recommended value of 0.4 based on the literary recommendation of Floyd and Widaman [26]. This indicates a significant correlation between the 15 items of the questionnaire and therefore the application of factorial analysis is justified. Based on the performed CFA analysis, the fit measures of the control model were determined, on the basis of which it is determined whether the control model satisfactorily fits the initial data. The values of individual parameters are shown in Table 3.

Table 3: Correlation matrix of latent variables

Fit indicators	Values for the control (measurement) model	0Values for the structural (PATH) model	Recommended values
Relative Chi-Square (χ^2 /d.f.)	2.50	2.50	< 3.0
Root Mean Square Error of Approximation (RMSEA)	0.09	0.09	< 0.08 – 0.10
Goodness-of-Fit Index (GFI)	0.93	0.93	> 0.8

Adjusted Goodness-of-Fit Index (AGFI)	0.87	0.87	> 0.9
Comparative Fit Index (CFI)	0.96	0.96	> 0.9
Incremental Fit Index (IFI)	0.93	0.93	> 0.9
Normed Fit Index (NFI)	0.90	0.90	> 0.9
Non-Normed Fit Index (NNFI)	0.90	0.90	> 0.9
Relative Fit Index (RFI)	0.93	0.93	> 0.9

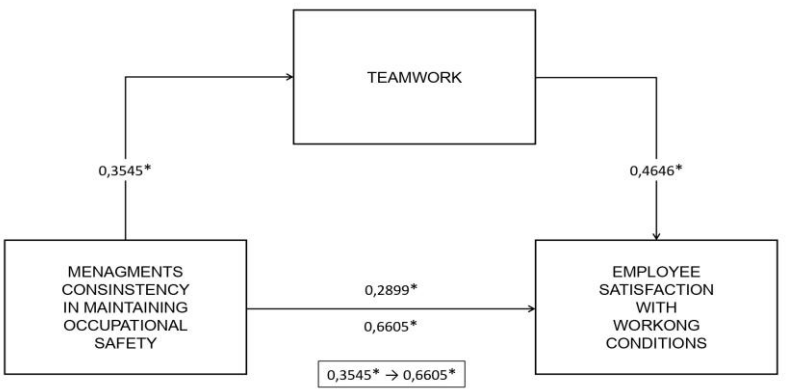
The correlation matrix of the control model are shown in Table 4. All correlation coefficients are positive and above the recommended value of 0.33, which points to the conclusion that there is a positive correlation between latent variables that are of practical importance. The level of statistical significance of correlation links is marked with stars. The level of statistical significance is shown in Table 5 and marked.

Table 4: Correlation matrix

No	Latent variables	1	2	3
1.	H1	1		
2.	H2	0.66*	1	
3.	H3	0.60*	0.77*	1

3.4. Structural model

The testing of the structural model, defined by the conceptual model shown in Figure 1, was performed after the validation of the control model and obtained satisfactory fit measures. The path analysis (Path Model Analysis) whereby the sequential relations in the defined conceptual model were determined. The obtained fit measures for the structural model are shown in Table 4 where, together with the fit measures of the control model, a comparison was made with the recommended values.



*$p < 0.01$

Figure 2: Structural model

The obtained values of fit measures for the control and structural models indicate the acceptability of the established conceptual model. The results of the analysis of the structural model are shown in Figure 2. Above the arrows are the values of the regression coefficients (β-coefficient of the path), which explain the strength of the relationship between the dependent and independent variables. The level of statistical significance is indicated by asterisks above the regression coefficients, and their value is shown in the note below the figure. Data in parentheses represent t-test values. The coefficients of determination (R^2) are shown in the fields of dependent variables, which show the participation of the explained variability in the total, that is, how much of the variation of the dependent variable is explained by the predictor variable.

Based on the obtained results of the path analysis, it can be observed that all the coefficients of the path (regression) have a positive value, which means that all three hypotheses are confirmed. In order to make a decision on accepting the hypotheses, an appropriate t-test was performed, and thus the statistical significance of the obtained results was determined. From the obtained results (Figure 2), it can be concluded that all three hypotheses are acceptable, because the t-test coefficients are above the recommended value of 1.96, according to the authors' recommendations [20-21]. The results of hypothesis testing indicate the fact that all three research hypotheses are confirmed, acceptable and statistically significant, because the following results were obtained: H1 (β=0.35; t=3.04; p<0.10); H2 (β=0.28; t=2.80; p<0.10); H3 (β=0.46; t=5.3; p<0.05). The coefficient of determination R^2 (Squared Multiple Correlations) is an index of the proportion of the variance of the endogenous variable, which is calculated over exogenous or predictor variables. After it was determined that all three prerequisites for mediation analysis were met, the defined variables were included in the mediation model to determine the type of mediation. The bootstrapping method was used to test the mediating effect [11]. Finally, if we look the results of the mediation model established in the research shown in Table 5.

Table 5: Results of the mediation model

Indirect Effect Estimation	Indirect Effect Coefficient S	Standard Error	Lower 95% Confidence Interval	Upper 95% Confidence Interva
Teamwork	0.1920	0.0475	0.0820	0.6605

F = 122.25; p = 0.00; Sobel Z = 5.3336; p = 0.00

The model constructed according to Table 5 shows significance with respect to the presented results (F = 122.25; p = 0.00). If we look at the lower and upper confidence intervals in the presented model, it can be concluded that the mediations do not result in a zero value [11], and the assigned mediation effect can be seen as statistically significant (Lower = 0.0820; Upper = 0.6605; Sobel Z = 5.3336; p = 0.00) [11]. In the specific model, the significance of the confidence intervals and standard errors of the residuals is estimated as the significance of the model in relation to the statistical interpretation of R^2 [11]. Therefore, in the bootstrapping resampling method, the percentages of reports are

considered, corrected for bias and a confidence interval in order to see the most robust results for estimating the mediator effect and the indirect effect.

Table 6: Results of hypotheses testing

Relationship	β	SE	t-Value	Hypothesis	Decision
H1→H2	0.3545	0.0452	3.04	H1	Supported
H2→H3	0.2899	0.0458	2.80	H2	Supported
H3→H2	0.4646	0.0363	5.35	H3	Supported
H1→H3→H2	0.6605	0.0454	16.69	H4	Partially supported

Finally, it was observed that the teamwork had a partial huge mediating role between management's consistency in maintaining occupational safety and employee satisfaction with working conditions (β´= 0.6605; t = 7.53; Sobel Z = 5.3336; p = 0.00) (Hypothesis H4). Consequently, the teamwork has a partial mediating role in the relationship between management's consistency in maintaining occupational safety and employee satisfaction with working conditions (Table 6). In other words, management's consistency in maintaining occupational safety affects the impact on teamwork, which in turn affects employees' satisfaction and safe behaviour.

4. DISCUSSION

4.1. Theoretical contributions

Based on the created questionnaire and formed groups of questions, hypotheses were discussed, as well as the relationship between it as influential factors in the development model. The results of the research show that teamwork had a huge mediating role between management's consistency in maintaining occupational safety and employee satisfaction with working conditions. Management that cares about the safety and well-being of its employees and that nurtures values and beliefs about the importance of safety influences safer behavior among employees [27]. This study provides empirical evidence directly linking worker perceptions of teamwork with subsequent organizational records of injuries, which fills an important gap in the research literature and presents an important opportunity for intervention to improve worker safety. Considering that, we research the most important elements of employee safety [28] in industrial processes of textile industry, as one of the largest and most complex sectors of industrial production. From all of the above, it can be concluded that modeling the risk factors at workplaces in industrial processes of textile industry with a predominantly female labor force can determine the level of safety development in an organization. Employee attitudes about workplace conditions and teamwork show positive impact on OSH in manufacturing companies. Finally, to ensure the safety of high-level employees, it is necessary to continuously analyze and improve the organizational occupational. In line with the aforementioned, the research in this paper can help organizations in linking certain factors of importance for evaluating the safety situation and forming a universal scale for measuring the development of the organizational safety climate.

4.2. Implications for practice

Modeling with the goal of predicting the outcome is the essence of scientific research, as evidenced by the growing trend of research works in this area. Modeling is also becoming an increasingly prevalent method when it comes to approaches to issues of health and safety at the workplace, and especially when researching the development of the safety at work in industrial sector of textile industry [29]. In this regard, the results obtained in this paper have a significant empirical contribution. The importance of the development of the level of safety at work stems from its impact on the operations and business results of companies in the industrial sector. Accordingly, the formation of a universal scale for measuring the development of the safety climate at work [30-31], thus creating an original and useful tool for managing the entire process of OSH and health management. Theoretically, the study increases the analysis of the impact of work environment factors on employee safety, especially in industrial enterprises with a predominantly female workforce. The study contributes to the theory by investigating the role of employment assistance on the association of job occupation factors with teamwork. The study also provides an opportunity for further research in this area.

4.3. Limitations and future directions

Basically, there are some limitations to this research. First, the sample size was limited which may affect the generalisability of results. Second, the respondents' opinion was sought through closed ended questions which may restrict the respondents to provide more insights into the phenomenon under study. Third, the study did not include only the qualitative opinion of employed women which limited the detailed response from the respondents. These limitations can be overcome in future research in this area. Also, more respondents, more organizations and more industry sectors can be included in order to increase the sample size and thus the results can be generalized to other industries.

5. CONCLUSION

According to the conducted analysis, modeling of safety factors in workplaces is extremely important in order to determine the level of risk to employee safety [30-32]. Starting from the basic hypotheses based on the obtained research results in the textile industry, it was concluded that teamwork has a huge mediating role between the consistency of management in maintaining safety at work and employee satisfaction with working conditions [33]. Finally, in the textile industry, performing work tasks is the result of creative ideas, collective knowledge, skills and experience, therefore, effective teamwork is key to ensuring efficient production processes and maintaining employee safety. Effective cooperation and coordinated teamwork also result in employee satisfaction with working conditions. Consequently, textile organizations can use the presented model in order to link certain factors of importance to the assessment of the state of safety, as well as to establish a universal scale that indicates the positive impact of teamwork on occupational safety and health in manufacturing companies. Increased commitment to the organization affects employees to feel valued and safe, and thus committed to their

organization. All this results in increased productivity, encourages better concentration and efficiency in this highly developed sector of industry in our country, especially in the world.

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GAMIFICATION AS MARKETING STRATEGY FOR LUXURY FASHION BRANDS

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ABSTRACT: *The present study explores the integration of gamification into the marketing strategies employed by prominent global luxury fashion brands, with a particular focus on Louis Vuitton, Gucci, Balenciaga and Burberry. Through the utilization of case study analysis and scholarly literature, the study explores the manner in which gamified experiences enhance consumer engagement, brand storytelling, and digital transformation. The findings demonstrate that gamification is not merely a marketing tool, but a strategic capability that redefines luxury branding in the digital age.*

Keywords: *Fashion, luxury, brand, marketing, gamification.*

GAMIFIKACIJA KAO MARKETINŠKA STRATEGIJA ZA LUKSUZNE MODNE BRENDOVE

APSTRAKT: *Trenutna studija istražuje integraciju gamifikacije u marketinške strategije koje primenjuju istaknuti globalni luksuzni modni brendovi, sa posebnim fokusom na Louis Vuitton, Gucci, Balenciaga i Burberry. Kroz korišćenje analize studija slučaja i naučne literature, studija istražuje način na koji gamifikovana iskustva poboljšavaju angažovanje potrošača, pripovedanje priča o brendu i digitalnu transformaciju. Nalazi pokazuju da gamifikacija nije samo marketinški alat, već strateška sposobnost koja redefiniše luksuzno brendiranje u digitalnom dobu.*

Ključne reči: *Moda, luksuz, brend, marketinga, gamifikacija.*

1. INTROUCTION

Digital age has profoundly and irreversibly impacted on the expectations of fashion consumers. Luxury fashion brands, traditionally reliant on physical craftsmanship, heritage

narratives, and controlled scarcity [1] now find themselves in an environment demanding digital interactivity, personalization, and immersive experiences. Simultaneously, engaging with the younger generations, which are characterized by their proficiency in digital technologies (Millennials and Gen Z), is of paramount importance in the context of ensuring long-term growth [2].

In fashion industry gamification has become a powerful tool in engaging and entertaining luxury consumers. In contrast to traditional advertising, gamification promotes interactivity, involvement, and emotional engagement, and as such is in harmony with the experiential values at the core of luxury consumption [1].

The term 'gamification' was originally coined by Bret Terrill [3] to describe the application of game mechanics to other web properties, for enhancing user engagement. However, it was not until 2010 that the term 'gamification' began to gain widespread use.

Gamification marketing, as defined as "the use of game design elements in non-game contexts" [4], offers an interesting potential. The utilization of elements such as points, badges, leaderboards, challenges, stories, and virtual rewards by companies is a practice employed to facilitate motivation, enhance learning, and create loyalty [5]. The worldwide luxury fashion industry incorporates fashion elements, such as skins or items, into popular video games with the objective of increasing user engagement and behavioural motivation. While gamification has seen widespread adoption across sectors such as education, healthcare, and mobile commerce, its application in luxury fashion marketing presents unique opportunities due to the sector’s symbolic value systems and emphasis on exclusivity. Luxury fashion brands, including Gucci, Louis Vuitton, and Balenciaga, have increasingly begun to implement gamified strategies in their digital marketing portfolios. Entertainment experiences represent a fundamental shift toward experiential value creation and co-creative brand engagement [6,7]. For digitally native generations -particularly Millennials and Generation Z- gamification aligns with preferences for interactivity, self-expression, and entertainment-driven commerce [8]. These consumers are not merely purchasers but active participants in brand storytelling ecosystems.

Gamified luxury strategies often emphasize narrative depth, aesthetic cohesion, and limited-access participation, reflecting the sector’s emphasis on identity, meaning, and cultural capital. The integration of gamification into luxury branding also reflects broader trends in virtualization of consumer culture. Collaborations with video games (e.g., Roblox, Fortnite, League of Legends) enable luxury brands to establish a presence in the online gaming environment. This process of recontextualization effectively redefines luxury consumption as a hybrid of physical, digital and experiential interfaces [9]. The integration of gamified products, including gamer skins and items, within the marketing landscape has emerged as a potent medium for conveying brand identity and values.

The present study shows a narrative (descriptive) approach to explore the way leading luxury fashion brands are employing gamification as a strategic tool to enhance digital engagement, strengthen emotional connections, and remain culturally relevant. The present paper reviews available literature on the subject to comprehend how luxury fashion brands are adopting gamification, their success, and the major considerations for successful implementation that preserve brand essence. It examines luxury fashion brands' use of gamification across global markets, evaluating strategic intent and real application. It

argues that gamification enriches digital engagement and brand storytelling while sustaining the aura of exclusivity and innovation consumers demand from luxury brands.

2. LITERATURE REVIEW

Deterding et al. [4] formalized gamification as the use of game design mechanics in contexts outside of games to produce engagement and motivation in users. It taps into intrinsic motivators such as autonomy, mastery, and purpose [10] rather than extrinsic rewards only. Gamification has now emerged as the main approach in sectors ranging from education [11] and healthcare [12] to e-business and e-marketing [5]. While gamification is increasingly tying itself in marketing to experience-driven value creation and co-creative brand relationships [13]. By applying mechanics such as points, levels, badges, and challenges, brands can increase more engagement and increase consumer time spent [14]. Recent case studies have explored the utilization of gamification as a marketing strategy by fashion brands. The gaming industry is the largest in entertainment, with younger millennials, Gen Z and Alpha consumers. For instance, [15] until recently, many individuals within the gaming population had no interest in, nor exposure to, fashion brands. The gamification approach facilitates brands in reaching a novel audience, encompassing not only younger demographics and crypto natives, but also those unreachable through traditional communication techniques by now.
Moreover, gamification evokes feelings of flow and immersion necessary for emotional attachment in digital brand environments [16]. Nevertheless, gamification in luxury brands is a complex terrain. Traditional luxury marketing relies on the tenets of scarcity, heritage, symbolism, and exclusivity [1, 17]. Ko and Megehee [18] would argue that luxury brands must preserve symbolic capital and aspirational distance even in digital settings. Thus, gamification in luxury must look beyond superficial interaction to offer aesthetically cohesive and brand-consistent experiences. This trend is backed by the growing luxury digital experiences literature. Kim and Sullivan [19] note that new generation consumers increasingly expect interactive, multisensory, and emotionally charged digital experiences with luxury brands. Gamification is one such tactical tool for delivering such experience, particularly when coupled with augmented reality (AR) and virtual reality (VR) or blockchain-based collectibles (NFTs) [20]. Luxury brands leverage these technologies to enter the metaverse platforms and design hybrid customer experiences, blending physical and digital brand touchpoints.

2.1. Virtual Luxury Fashion Consumption

Virtual consumption has introduced fresh paradigms of luxury brand engagement. Luxury skins get embedded in consumer avatars and virtual worlds, being centred on personalization and in-game interaction [21]. This transition from material to virtual luxury consumption necessitates a re-evaluation of the dynamics of exclusivity and status within virtual environments by brands. Research on virtual luxury consumption reveals that consumers' purchase intention of luxury brands' digital fashion is influenced by factors distinct from traditional luxury consumption drivers [22]. Knowing these factors is vital

for creating effective gamification strategies that appeal to digital natives while protecting a luxury brand's value. Gamers associate items or skins more with their virtual characters than with the luxury brands themselves. Virtual luxury fashion is distinguished by its technological features, such as blockchain, in-game trading and gifting systems, catering to different audiences, price points and experiences [23].

3. APPROACH TO CASE SELECTION AND EVALUATION

This review employs a narrative (descriptive) approach to explore how gamification is integrated into the strategies of major luxury fashion houses. The cases of Gucci, Louis Vuitton, Balenciaga, and Burberry were selected due to their prominent positions in the global luxury market, their cultural significance, and their well-documented engagement with interactive technologies targeting digital consumers. These brands were identified through a preliminary survey of academic literature, industry reports, and reputable media coverage on luxury gamification trends. No systematic inclusion or exclusion criteria were applied; rather, the cases were chosen for their illustrative value in demonstrating varied and significant approaches to gamification within the luxury fashion sector.
Each case was selected to represent a distinct perspective on how gamification aligns with brand heritage, market position, digital maturity, and approaches to constructing luxury identity in the digital age. The cases were described in detail by analysing publicly available data on gamified campaigns—including narrative elements, technological platforms, and consumer engagement strategies. Emphasis was placed on the depth, intent, and brand alignment of each gamification strategy, with particular focus on how these initiatives reflect the brands’ efforts to reinforce exclusivity and authority within luxury culture.

3.1 Case Selection

Four top luxury fashion houses were selected for their gamification investments and market leadership: Louis Vuitton, Gucci, Balenciaga, Burberry. The brands cover different luxury fashion segments and have implemented different gamification solutions, providing a rich comparative context.

3.2. Case studies

3.3. Louis Vuitton

With eight million players accessing the game simultaneously each day, League of Legends (LoL) is a team-based strategy game in the multiplayer online battle arena (MOBA) genre. Nicolas Ghesquière, the artistic director of women's collections, designed a limited-edition Louis Vuitton 'prestige skin' for LOL in October 2019. The objective of this collection is to explore the potential impact of a character created within a digital context on real-world society, and to examine the motivations behind individuals emulating the appearance of such characters. Ghesquière's contribution to the realm of esports was marked by the creation of virtual outfits, or 'skins', for Qiyana and Senna, two prominent champions in the game League of Legends. True Damage Qiyana Prestige Edition skin and True Damage

Senna Prestige Edition skin were obtained through in-game means or procured if the player's combat proficiency falls below the requisite level [24].

Figure 1: League of Legends True Damage' “Prestige Edition Skin”, Louis Vuitton, 2019.

To blend brand heritage with technology and celebrate 200th anniversary, Louis Vuitton launched a mobile game app called “Louis: The Game” mobile game app in August 2021. The adventure third-person game follows the brand's virtual mascot Vivienne on a world tour to collect 200 candles representing landmarks in the brand life. The game is not only rich in storytelling heritage but also multilevel with digital innovation has incorporated NFTs (non-fungible tokens) developed by contemporary digital artists such as 'Beeple'. The introduction of NFTs was both a marketing novelty and a strategic statement, solidifying Louis Vuitton's position as an innovative luxury brand open to the Web3 economy. The NFTs randomly won inside the game were non-tradable, ensuring exclusivity and preventing brand value dilution. Moreover, the game was updated in 2022 with new levels and storyline options, proving the brand's long-term investment in consumer engagement [25]. The game has now been downloaded two million times and counting. Considering this popularity, the luxury brand has decided to continue the video game's quest with the lead avatar, Vivienne. New game levels, 'Radiant City' and 'High in the Sky', were added in 2022, allowing players to unlock more secrets of the brand's iconic history. Vivienne NFTs can be used as an avatar on social networks and are portable across other platforms (Showstudio, 2022).

Figure 2: “Louis: The Game” avatar ‘Vivienne’ featuring various traits and designs, Beeple NFTs, 2021

“Louis: The Game” illustrates a wise equilibrium of education, entertainment, and selectivity. It also illustrates the brand's adaptability in using gamification to brand mythologizing, where virtual world storytelling reinforces its cultural capital.

To celebrate a year on the Discord platform, Louis Vuitton launched an immersive digital quest called Enigma in November 2024, captivating its community. In five days from November 26-30, two factions formed of the Maison community of 8,000 individuals received a daily puzzle to find Vivienne, Louis Vuitton's mythical mascot, who had gone missing. Enigma was the personification of the House's travel inspirations and of the codes of gaming culture in perfect measure, with courage and innovation [25].

Figure 3: “Enigma”, Vivienne LV’s iconic mascot, who had disappeared., Louis Vuitton, 2024

3.4. Gucci

Gucci collaborates with video games and self-expression platforms enhances the good values that are essential to provide a gaming experience from 2020. Gucci's entry into video game platforms with fashionable items is consistent with an open-arms approach that encompasses a variety of creatives in the development of realistic experiences designed to close and deep relationships with players. Over the years, initiatives have resulted in the brand partnering with XBOX (2021) to offer *Tennis Clash* (2020), *The Sims* (2020), *Hot Wheels Unleashed* (2021), *Pokémon GO* (2021), *Animal Crossing* (2021), *Zepeto* (2021), *Roblox* (2022), *The Sandbox* (2023) or a limited-edition bundle on a select number of games. In 2020, Gucci presented ‘Off the Grid’ collection, showcasing the work of two exclusive content creators who are part of the Sims community and the first digital twins of a sustainable fashion line. Gucci Off the Grid pieces in the game give players a green eco-footprint, an environment score of 10, and raise Sim characters' moods [27].

Figure 4: “Gucci Off the Grid”, Gucci x The Sims 4, 2020

Introduced in 2022, “Good Game” capsule collection represented the guiding principle of the fashion house's venture into the world of gaming. Two letters encoded with House’s century-old DNA were rebranding with the video gaming. When it was launched in conjunction with the Gucci Gaming Academy e-sport sponsorship announcement the e-

sportsmanship salutation "GG" or "Good Game" became the name and motto for Gucci's ventures into virtual worlds. This collection digital twin featured a special item package edition in Roblox Gucci Town [28].

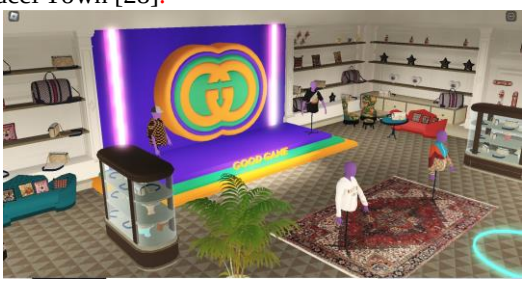

Figure 5: “Good Game” theme in Roblox Gucci Town, Gucci x Roblox, 2022

The Sandbox, a decentralized game ecosystem, is a remarkable example of this shift towards player-created content. A digital experience that mirrors the archival Gucci exhibition arrived in The Sandbox in 2023. While Gucci Cosmos was opened at 180 Studios in London, a similarly immersive journey through the House's past, present, and future experienced within The Sandbox Metaverse. The exhibition comprised various interactive games, digitized exhibition worlds and archival pieces, which collectively trace the origin stories of the House and its codes [29].

Figure 6: **“**Gucci Cosmos Land”, Gucci x Sandbox, 2023

The integration of Gucci within virtual ecosystems facilitates the democratization of the brand while maintaining its prestigious status. Gucci uses digital environments to preserve luxury brand image while increasing recognition among younger users. From a market positioning perspective, gamification has also helped Gucci rejuvenate its image, transitioning from heritage to postmodern icon. Moreover, the integration of scarcity mechanisms, such as limited time drops and collectible digital goods, aligns with the luxury industry's emphasis on rarity and symbolic differentiation.

3.5. Balenciaga

Epic Games collaboration with fashion house Balenciaga to bring the first ever high fashion skins into the world's most popular online battle royale game, Fortnite in 2021. Users had

the opportunity to purchase items for their avatars, such as virtual clothes, backpacks and accessories, in a range called the “Balenciaga Fit Set”. These cosmetic game items were creating a two-way experience between virtual and physical retail after the launch. At the same time, Balenciaga boutiques showcased Fortnite-themed window displays and limited-edition clothing, seamlessly combining the worlds of gaming and high-end street fashion [31]. This is a fine example of gamification marketing, involving an understanding of and ability to leverage video game cultural norms and gamer habits to develop a stronger brand presence among digital natives. Balenciaga's gamification approach is about visibility and cultural signaling. By associating with Fortnite, the brand aligns itself with non-conformity, irony and aesthetic risk, hallmarks of its creative direction under Demna Gvasalia. This creates a tension between exclusivity and accessibility, reinforcing Balenciaga's disruptive image while expanding its reach.

Figure 7: “Balenciaga Fit Set”, Balenciaga x Fortnite, 2021

Balenciaga's “Afterworld: The Age of Tomorrow” is a video game designed to showcase the brand’s Fall 2021 collection. Consumers navigated a virtual landscape, exploring and engaging with the latest products in a dynamic and memorable manner. This blurring of the lines between advertising, entertainment, and the luxury product experience is outstanding in contemporary marketing. The project was characterised by a collaborative nature, with contributions from various studios (Substance & Inhalt, Yumebau Inc, Streamline Media Group, Dimension Studios) and creators across the globe. Balenciaga's Creative Director, Demna Gvasalia, provided the creative vision, which included the conceptualisation of the video game and the design of its virtual environment [32].
The generation of rich behavioral game data is facilitated by engaging interactions, the expression of preferences via game choice behavior, and play patterns, as well as interaction with virtual items. The collation of this data will facilitate the personalization of future marketing campaigns and product recommendations to an unprecedented degree.

Figure 8: “Afterworld: The Age of Tomorrow”, Balenciaga**,** 2021

Since 2017, French composer and musician BFRND has been creating original music for each Balenciaga show, redefining the boundaries of the fashion show by blending dark electronic rhythms with classical touches. Transcending genres, BFRND's work has become a key element in Balenciaga's avant-garde creative expression. The series, dubbed the Balenciaga Music | BFRND, comprises limited-edition merchandise, an original playlist of 4 hours in duration, curated by BFRND and featuring influences on his artistic practice, and an original video game, offering 360° experience. Balenciaga realized second video game is an 8-bit nostalgic game called “BFRND: The Game”. As a designed BFRND character, the objective for players is to navigate around each presentation's obstacles while collecting iconic Balenciaga products to score points. Accessible on a dedicated mini-site, WeChat and the Balenciaga Paris Montaigne and Shanghai IAPM flagship store touchscreens [34].

Figure 9: “BFRND: The Game”, Balenciaga**,** 2024

3.9. Burberry

Burberry has established itself of digitally networked gamification within the luxury space, deploying interactive marketing such as *B Bounce* (2019), *B Surf* (2020), *Burberry Hero Game* (2021), in-game partnerships (Honor of Kings x Burberry skins, 2021, Roblox items, 2022), *Sharky B* player skin and item NFTs (Burberry x Mythical Games-Blankos Block Party, 2021), *Burberry Blanko*, *Minny B* player skin and item NFTs (Burberry x Mythical Games-Blankos Block Party, 2022), augmented reality (AR) filters (Shenzhen store WeChat app and Tokyo store Google Search, Snapchat, 2020) to construct experiential experience with next-gen consumers. This is a sign of gamification marketing campaigns that blend heritage conventions with digital immersion, personalization and social sharing.

B Bounce online game is indicative of casual gamification; wherein straight forward mechanics are employed to build consumer interest and interaction [34]. B Bounce is part of a wider experiential marketing strategy, creating non-transactional touchpoints that cement emotional brand relationships and extend time spent on brand content. AR filters across Snapchat and WeChat, digital try-ons, and virtual tours of stores allow users to play with Burberry products in playful, immersed environments. Burberry thereby generates affective interaction especially with younger, mobile-first consumers.

In 2021, Tencent's Honor of Kings (MOBA genre game 100 million average daily active users) Burberry released in-game skins designed by Riccardo Tisci, injecting Burberry's symbols into the world of the game [35]. It is a step that is in line with what have established as symbolic consumption in virtual environments, in which luxury brands are identity marks not only in the physical but also in the gaming industry.

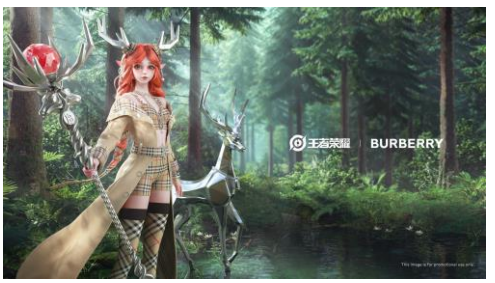

Figure 10: “Spirit of Nature”, Honor of Kings x Burberry, 2021

Minecraft is the most popular survival video game with 1.2 million daily players. In 2022, the brand collaborated with Minecraft on an in-game adventure called 'Burberry: Freedom to Go Beyond'. In-game adventure map includes 15 Burberry skins, from stylish outfits to armor and even elemental-themed skins. Consumers were allowed to immerse themselves physically and digitally through in-game skins and experiences produced as a capsule collection in real life. The collection features an unconventional combination of traditional Burberry garments and prints inspired by the Minecraft video game, with the objective of transforming daily clothing items and inspiring contemporary explorers [38].

Figure 11: “Burberry: Freedom to Go Beyond”, Minecraft x Burberry, 2022

In 2022 July, Burberry introduces virtual handbag collection on an immersive online platform Roblox (50 million daily active users). Taking inspiration from the brand's iconic Lola bag and Burberry's affinity for nature and the outdoors, the exclusive limited-edition virtual Lola range comprises five unique handbags [36]. In February 2024, two years later, Burberry launched Harrods takeover on Roblox. The launch invites Roblox's global community to explore the digital extension of Burberry at Harrods, celebrating its heritage of exploration and the outdoors. The Harrods facade is recreated as a Burberry-branded virtual storefront, reimagining awnings and window displays. Furthermore, users have purchased digital Burberry items, including scarves, hot water bottles and horse-shaped carabiners, for the purpose of customizing their avatars on the platform [37].

Figure 12: “Harrods takeover”, Burberry x Roblox, 2024

Table 1: Studied brands and games characteristics

Brand	Game	Avatar	Skin	Item	Capsule Collection/ Collection	Reward	In Game Purchase
Louis Vuitton	League of Legends		x		x		x
	Louis: The Game	x	x	x		x	
	Enigma	x					
Gucci	The Sims 4		x	x	x	x	x
	Roblox		x	x	x		x
	Sandbox		x			x	
Balenciaga	Fortnite		x	x	x		x
	Afterworld: The Age of Tomorrow	x	x		x		
	BFRND: The Game	x	x	x	x	x	
Burberry	Honor of Kings		x		x		x
	Minecraft	x	x	x	x	x	
	Roblox		x	x	x		x

4. DISCUSSION

The present analysis of gamification regarding major luxury fashion houses (namely Louis Vuitton, Gucci, Balenciaga, and Burberry—shows that while each brand actively utilizes interactive technologies to engage digital consumers, the purpose, depth, and alignment with brand identity differ markedly. These differences stem from the unique blend of each brand's heritage, market status, level of digital sophistication, and their individual strategies for constructing a luxury identity in the digital context.

Louis Vuitton adopts a heritage-driven, narrative gamification approach, as illustrated by *Louis the Game* and *Enigma*. Its gamified strategy interweaves brand storytelling, gamified learning, and digital collectibles (NFTs), emphasizing educational immersion with recreational play. The brand leverages its history to construct prestige through interactivity, thus aligning with the concept of luxury brand storytelling. Louis Vuitton's art-directed gamification reinforces exclusivity and the brand's authoritative position within luxury culture.

Gucci's strategy demonstrates a form of experiential gamification that amplifies symbolic value through playful surrealism and metaverse positioning by *Roblox* and *Sandbox* collaborations. Rather than focusing solely on boosting brand visibility, Gucci's gamification enhances brand awareness creating brand universes which contributes to long-term identity differentiation among digital natives.

Balenciaga gamification strategy exemplifies cultural convergence, enabling high fashion to blend with mass entertainment. Balenciaga's presence in gaming environments functions as symbolic penetration, challenging traditional luxury codes through digital democratization. Here, gamification becomes a medium of brand commentary, reinforcing its rebellious and postmodern image. The integration of traditional brand heritage with digital futurism is of interest to both traditionalists and digital natives alike, without compromising its prestige, further expanding its resonance.

Finally, Burberry demonstrates how luxury can succeed in light-hearted, interactive digital environments without eroding brand value. With initiatives like *B Bounce*, augmented reality collaborations, and gaming partnerships, Burberry positions itself as a participatory luxury brand that cultivates emotional engagement, sparks social interaction, and strengthens cultural relevance.

5. CONCLUSION

Gamification has become a key driver of marketing initiatives in the world's luxury fashion brands, as they seek to connect with digitally engaged consumers through interactive, immersive, and emotionally stimulating experiences. The extant literature generally suggests that gamification, when incorporated into a well-considered strategy, can serve as an effective digital marketing tool. It provides tools for driving engagement, enriching brand narratives, and developing emotional connections with the future generation of consumers.

An analysis of gamification efforts across brands including Louis Vuitton, Gucci, Balenciaga, and Burberry demonstrates that gamified marketing can meet a variety of strategic goals—from amplifying brand narrative and consumer interaction to powering digital innovation and cultural relevance. Although various brands engage with gamification in distinct manners—shaped by their historical context, intended audience, and unique brand identity—certain recurring themes can be identified. Among these are the preference for video game centric design, the incorporation of augmented reality and virtual reality technologies, and the employment of interactive narratives to enhance consumer engagement and emotional connection. Additionally, gamification has demonstrated its adaptability as a strategic instrument, adept at promoting both exclusivity and inclusiveness, contingent upon its implementation within the wider branding framework. At a strategic level, gamification allows luxury brands to go beyond the constraints of older media, providing customers with not just products but experiences, identity, and digital artifacts as well. This is consistent with the larger transition from a goods-based to an experience-based luxury paradigm. By engendering co-creation, customization, and emotional value, gamification helps create long-term brand equity in a competitive and digitally dynamic market. However, integrating gamification into luxury branding presents certain challenges. Brands are tasked with maintaining an equilibrium between playfulness and prestige, steering clear of excessive commercialism, and safeguarding that technological advancements do not compromise essential luxury values like craftsmanship, heritage, and symbolic significance. The design of gamified experiences must therefore be congruent with brand identity and culturally sensitive to win heartstrings in global markets.

In conclusion, gamification is reshaping the meaning of luxury, offering new pathways for emotional connection, digital engagement, and brand innovation. As consumer expectations continue to evolve in the post-digital age, luxury brands must embrace gamification as an integral component of brand storytelling and value creation.

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APPLICATION OF 3D SKIRT DESIGN IN THE CONTEXT OF EFFICIENCY AND SUSTAINABILITY

Original scientific paper
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ABSTRACT: *Considering the rapid changes in the fashion and clothing industry, digital technologies represent an important tool for improving the efficiency and sustainability of production processes. This paper explores the application of 3D software tools in the skirt design process, with a particular focus on time savings, waste reduction, and visualization capabilities prior to making the first trial sample. Using CLO 3D software, a digital model of the skirt was developed and compared with the conventional approach in Modaris software. The analysis includes a comparison of the duration of production, flexibility during changes, visual control. The conducted analyse show that the 3D construction and visualzation enables faster design iteration and a reduction in the number of sewn first samples, which contributes to sustainability through a more rational use of materials. It can be concluded that the integration of 3D programs for the construction and visualization of garments represents a significant step towards the digital transformation of the fashion industry.*

Keywords: *3D design, CLO 3D, Modaris, sustainability, skirt.*

PRIMENA 3D PROJEKTOVANJA SUKNJE U KONTEKSTU EFIKASNOSTI I ODRŽIVOSTI

APSTRAKT: *Uzimajući u obzir brze promene u modnoj i odevnoj industriji, digitalne tehnologije predstavljaju važan alat za poboljšanje efikasnosti i održivosti proizvodnih procesa. Ovaj rad istražuje i analizira primenu 3D softverskih alata u procesu konstrukcije suknje, sa posebnim fokusom na uštedu vremena, smanjenje otpada i mogućnosti vizuelizacije pre izrade prvog probnog uzorka. Koristeći CLO 3D softver, razvijen je digitalni model suknje i upoređen sa konvencionalnim pristupom u Modaris softveru.*

Analiza obuhvata poređenje trajanja proizvodnje, fleksibilnosti tokom korekcija i izmena, i vizuelnu kontrolu. Sprovedena analiza pokazuje da 3D konstrukcija i vizuelizacija omogućavaju bržu iteraciju dizajna i smanjenje broja sašivenih prvih uzoraka, što doprinosi održivosti kroz racionalniju upotrebu materijala. Može se zaključiti da integracija 3D programa za konstrukciju i vizuelizaciju odevnih predmeta predstavlja značajan korak ka digitalnoj transformaciji modne industrije.

Ključne reči: *3D dizajn, CLO 3D, Modaris, održivost, suknja.*

1. INTRODUCTION

In recent years the fashion industry has been going through a significant transformation due to the impact of sustainability, digitalization and increasingly demanding consumer needs. In this context, digital technologies, especially 3D software for clothing design and production, are becoming key tools for improving the design, production and evaluation processes of clothing products. In a modern environment, where speed of product launch on the market, waste reduction and resource optimization are of crucial importance, 3D design can provide efficient planning, visualization and testing of garments even in the developing stage, without the need to create physical prototypes of clothes samples [1-3].
At the same time, growing demands for sustainability in the fashion industry are directing attention towards technologies that enable the reduction of material, energy and time consumption, while simultaneously preserving the aesthetic and functional qualities of the product. Digital fashion and virtual prototypes represent an alternative to traditional production, contributing to the reduction of the ecological footprint through virtual collections, 3D trial and a reduced number of physical samples [3,4]. Companies such as Nike, Adidas, Zara, Hugo Boss and others are already demonstrating how 3D technologies and digital tools can become part of a wider sustainability strategy [5-7].
According to the results of some research, the great pressure on designers is related to the speed of placing the product on the market. A faster and faster launch of collections is required in order to achieve continuity in renewing the offer in stores. Research and application of digital and virtual technologies in the field of clothing design are of great importance in the transformation of the clothing and fashion industry, which is based on value propositions that integrate ethics, aesthetics and innovation. New digital technologies are leading the textile industry towards the 4.0 industrial revolution, which is aimed at creating smart products, processes and the entire production [8].
The use of 3D skirt designs as a specific garment is an example of how digital tools can be integrated into practice with the aim of increasing environmental, economic and production efficiency. Thanks to software such as CLO 3D, Browzwear and others, it is possible to precisely develop models, visualize the silhouette on the avatar, simulate the fall of fabric and optimize material consumption without physical tests [3, 4].
This paper analyzes the application of 3D skirt design as a methodological framework for process improvement in terms of production time, material consumption, reduction of physical samples and communication between actors in product development. Special emphasis is placed on the comparison between traditional (2D) and modern (3D)

approaches to clothing design, as well as on the possibilities that 3D design offers in the field of sustainable development of the fashion industry [1, 4, 8].
The aim of the work is to examine to what extent and in what way 3D design contributes to increasing efficiency and sustainability in the process of developing clothing products, with a special focus on the skirt as a model that is representative and suitable for virtual testing. This work contributes to contemporary research in the field of digitization of fashion, sustainable design and technological optimization of product development.

2. DEFINITION OF DIGITALISATION AND ITS IMPORTANCE IN THE CLOTHING INDUSTRY

Digitization represents one of the key technological changes that is shaping the ways in which businesses function, communicate and develop products. Although the term digitization is often used in different contexts, its meaning is still not unambiguously defined in professional and scientific literature. Depending on the context and industry, digitization can mean different levels of transformation – from a simple transition from analog to digital records, to deep changes in business models with the use of artificial intelligence, machine learning and process automation [2, 9, 10].

Figure 1: 3D product design by Adidas created using Browzwear software [https://dtech.fitnyc.edu/projects/adidas-browzwear].

In business practice, digitization is most often used to describe the process of converting analog information into digital records, which can then be used to improve efficiency through structuring, standardization, and automation of activities [2, 9]. The basis of that process is the electronic collection, processing and analysis of data, which enables strategic and operational decisions to be made in real time.
In the clothing industry, digitization has multiple applications – from digital garment design, through virtual prototyping and 3D design (Figure 1), to production automation, digital marketing and e-commerce. This industry uses digital tools to respond to the ever-increasing demands of the market for faster product development, personalization, supply chain transparency and sustainability [1, 2, 10].

By using 3D software solutions, it is possible to reduce the number of physical samples, speed up the decision-making process and improve cooperation between designers, manufacturers and retailers [10].

3. DIGITAL TECHNOLOGIES AS TOOL FOR IMPROVING SUSTAINABILITY IN CLOTHING DESIGN

Digital technologies have multiple effects on improving sustainability in the fashion industry. Their application enables more efficient use of resources, reduction of waste, optimization of the production process and greater transparency in the supply chain.

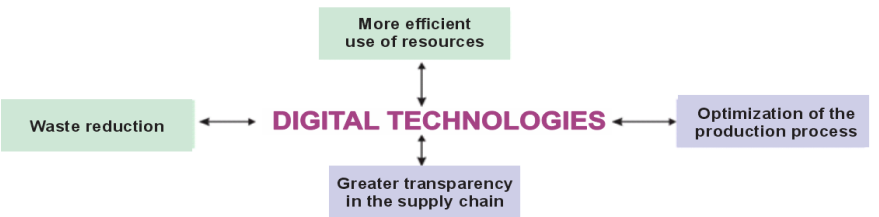


Figure 2: The impact of digital technologies on sustainability through key production segments (figure created by author).

Automation of processes and work with digital tools open up new opportunities for personalized production, flexible working environment and reduction of stocks, i.e. overproduction, which is one of the biggest problems of the fashion industry. By using big data analytics and predictive algorithms, it is possible to predict demand more accurately and thus avoid stoks [10 -13].

Traditional models of collection development relied on multiple physical prototyping, manual construction of cuts and the creation of waste in the process of experimentation. With the introduction of tools for computer-aided design (CAD), 3D simulation, parametric modeling and digital prototyping, designers and constructors today have the ability to make informed and responsible decisions in the early stages of the process [12,13]. One of the most important contributions of digital tools is the 3D visualization of clothing models using software such as CLO3D, Browzwear or Optitex. These tools enable virtual testing of construction, fit, material fall, silhouette and size – without the need to physically make samples. In this way, textile waste, the number of physical prototypes and the total consumption of materials are significantly reduced [12,13].

CAD systems for construction and tailoring, such as Lectra, Gerber and Modaris, enable the precise construction of clothing forms, automatic grading of sizes and optimization of the arrangement of cutting parts, which achieves the maximum utilization of materials [14]. Integrating these systems with fabric databases and virtual avatars further improves design accuracy and shortens collection development time. 3D design and visualization open significant opportunities for the development of the concept of fashion on demand, which contributes to personalization and mass customization, thus producing pieces that meet the

real needs of consumers, reducing stock and increasing the likelihood of long-term use of clothing items [15]. Through parametric tools, it is possible to change dimensions, style, colors and materials without the need to reconstruct the basic model, which supports a sustainable approach to "designing for reuse" and "product longevity" [3, 6]. In addition, digital technologies in design enable real-time collaboration between designers, construction teams and clients. By using digital platforms to exchange visuals and technical specifications, faster validation of ideas is enabled, thus reducing development time and the number of iterations [1, 7].

4. APROACHES TO 3D CLOTHING DESIGN

The development of 3D simulation tools in the fashion industry intensified during the 1990s and 2000s, where two key approaches were distinguished:

- "3D in 2D" - Creating a design directly on a 3D avatar, after which the molded parts are converted into 2D tailoring elements.
- "2D in 3D" - A more traditional method where 2D cut pieces are placed on virtual mannequins or avatars to simulate the appearance of clothing in the digital space.

These approaches enable optimization of the entire design and production process, reducing costs and time needed to finalize collections.
Sometimes these two approaches are combined to develop advanced CAD systems. Today, a large number of 3D CAD software for design and virtual prototyping of models are available, commercially offered by the companies shown in Table 1 [16].

Table 1: Comparison of the characteristics of modern 3D software in the context of application in the fashion industry

Software	Application	2D/3D support	Simulation	Price
CLO 3D	industrial design	Yes	Realistic	Low
Browzwear Vstitcher	Industrial product development	Yes	Advanced	High
Optitex 3D	Serial production	Yes	Advanced	High
Marvelous Designer	industrial design, animation	No/only 3D	Visual	Low
Styler 3D (Linctex)	3D design, virtual rendering	Yes	Realistic	Middle
Modaris 3D Fit (Lectra)	Industrial product development	Yes	Advanced	High
Tuka 3D (Tukatech)	Industrial product development	Yes	Advanced	High
Gerber Accumark 3D	Industrial product development	Yes	Advanced	High
Audaces 360	Industrial product development	Yes	Realistic	Middle

5. EXPERIMENTAL PART

Despite the increasing availability and development of advanced digital tools, the practice of designing clothes in most fashion companies in Serbia still dominantly relies on traditional CAD systems, such as Lectra, Gerber and Optitex. These tools are primarily used for construction, grading and preparation of custom parts, while their potential for 3D simulation and virtual prototyping is rarely used to its full capacity.
Based on practical insights and cooperation with the domestic industry, it can be concluded that a small number of brands have licenses for 3D software such as CLO 3D, VStitcher, Optitex 3D, but even when they are present, these tools are most often not actively used in everyday practice. The lack of trained staff, getting used to older work methods, as well as the initial investment in training and integration of new tools, are the main obstacles for the wider application of 3D design in the domestic context.
For this reason, the experimental part of the work was designed to compare two approaches to the development of the same model of a women's skirt. As a basis for comparison, a skirt model was chosen that was realized in two ways:

- The first approach relies on the method that is most often used in domestic companies, that is, on manual digitization and modeling in Modaris (Lectra) software, which is the standard in most companies in Serbia.
- Another approach involves the application of a modern software solution for 3D design and visualization in the CLO 3D program, which enables virtual testing of the construction, appearance and behavior of materials on an avatar.

5.1. Methods

5.1.1. CLO 3D

The CLO 3D program was developed by a team of experts at the Korean company "CLO Virtual Fashion Inc." and was presented for the first time in 2009. It enables the simulation of garments in a virtual space before the start of production. Over the years, CLO 3D has experienced dynamic development, with frequent upgrades bringing new advanced cut and fabric simulation tools, improved user interface, and better integration with other software solutions [8, 11].
CLO 3D enables the creation of digital clothing prototypes that can be viewed from all angles, i.e. in a 3D virtual space, while simulating the fabric's behavior in real conditions [8]. Key functions of the CLO 3D program:
• 2D Tools for drawing basic cuts (line, curve, internal line, dart...)
• 3D Simulation and realistic visualization of cuts in 3D space with a momentary trial of the garment on a virtual avatar
• Display Avatar and adjust body measurements
• Fabric library with physical parameters (thickness, elasticity, friction...) with the possibility of importing your own textures and pattern mapping
• The sewing simulation function, that is, the joining of parts as in reality with the simulation of stretching, wrinkling and layering of seams.
• Ability to display material tension on seams (strain map)
• Export of high-resolution images and 360° display of models and interactive presentations
• Ability to export and import files in PDF, DXF, AI formats [8, 11].

5.1.2. Lectra- Modaris

Modaris is a software package that has the possibility of digitization, computer construction, modeling and grading of tailoring parts, as well as creating variants of clothing models [17].

Lectra is one of the leading manufacturers of computer CAD systems in the textile industry. It was founded in 1973 in France, and the Modaris program was released in 1984. the program provides tools for creating basic constructions, modeling different stylistic variants, as well as automatic or manual grading of sizes. The use of Modaris contributes to greater precision, efficiency and consistency in the development of apparel products, thereby reducing the need for physical prototypes and speeding up the entire collection development process. The software is used in education, design and industrial production. There are two ways of making tailoring parts in a computer program. One is direct construction in a computer program, while the other involves manual construction on paper and then transferring the cut parts through a digitization process to the computer [17].

5.2. Materials

Description of the skirt model. The skirt model shown in Figure 3 is an asymmetric skirt with a flap that closes with two decorative buttons placed on the upper part of the front. The skirt is of medium length and follows the body line. The size in which the skirt was made is 38.

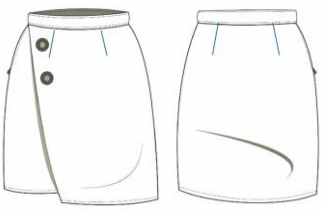
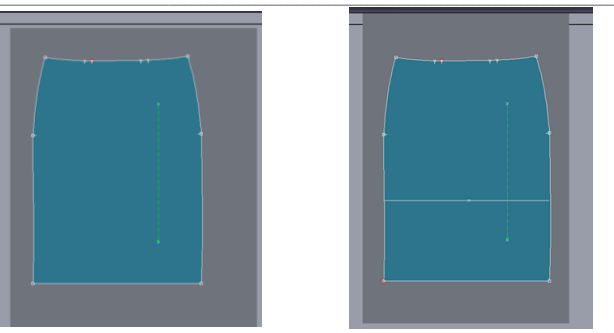


Figure 3: Technical sketch of the skirt model

In Modaris (Lectra) software, the basic cut of a woman's skirt was first digitized, whereby the paper cutas transferred to a digital format using a digitizer. After the successful digitization, the modeling phase was started, where the original cut parts were modified in accordance with the design solution. The process of creating a model of a women's skirt in the Modaris program consists of the following stages:

1. Digitization of the basic cut
   - The paper cut of the woman's skirt was transferred into digital format using a digitizer.
2. Preparation of the front part for modeling
   - The front cut is symmetrically opened using the Symmetry function over two points (F5) along the front center line. (Figure 4a)
   - Unnecessary type 2 points were removed with the Fusion function (F3), then converted to type 1 points and deleted. (Figure 4b)



a) b)

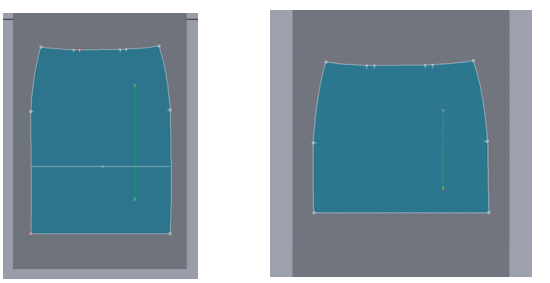
Figure 4: a) Opening the front cutting part, b) erasing unnecessary points

3. Changing the length of the cutting parts

• Markings of the new length of the cutting parts by adding Relative points on the contour reduced (picture 5a),

• Creating a parallel line. The exact values of the positioning of the relative point and the cutting parts are entered in the dialog box (Fig. 5a).

• By activating the function of cutting across two points, the new length of the cut parts is defined (picture 5b).



a) b)

Figure 5: a) Determining the new length of the skirt, b) the front cut part of the skirt with the remodelled length

4. Duplication and separation of cutting parts

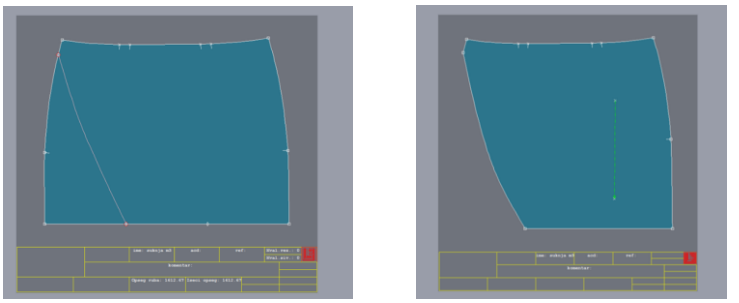
• The cutting part is duplicated using the F1 function (click on the line and move), defining the distance with the entered value.

• The cut function (F4) draws an internal line and separates it as a separate part.

6. Preparation of cutting points

• The relative point is placed 3 cm from the waist on the hip line - it represents the starting point for cutting the upper front part.

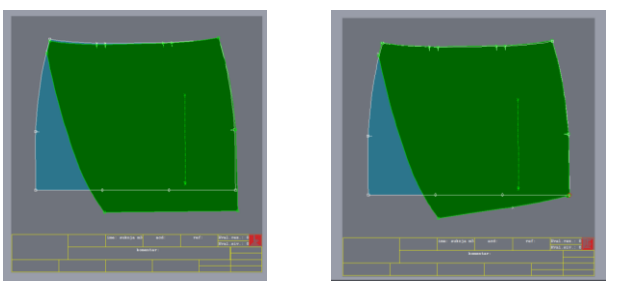
• Using a Bezier line, a cutting line for the folding front part was created



a) b)

Figure 6: a) adding a relative point and creating the cutting line of the front part, b) cutting the cutting part along the drawn curved line.

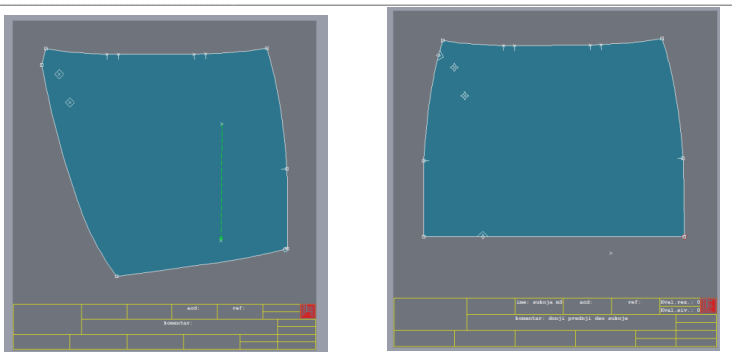
7. Sharing the model and shaping the curved lines
   - The sequence is divided into three parts to obtain a 2/3 skirt (Figure 6a).
   - Bezier line (F1) was used while holding the Shift key to obtain the desired curve.
8. Cutting along a curved line
   - With the F5 function, the cutting part is cut according to the constructed curved line.
   - The points on the curved line are simplified with the F5 function, for smoothness.
   - Reshaping the line along the length of the new cutting part (Figure 6b)
9. Assembly and centering of parts
   - The Bezier line was used to center and shape the cut parts.
   - The F3 function centers the parts to match the corresponding points (Figure 6)



a) b)

Figure 7: Reshaping the length line and assembling the cut parts of the skirt

10. Marking button positions
   - The buttons are marked with a relative point and a species designation of 37.



a) b)

Figure 8: a) marking the position for sewing on holes, b) positioning the place for sewing on buttons

11. Assembling the back of the skirt

• The F8 function was used to mount the rear part and reshape it

Procedure for creating a skirt model in CLO 3D:

1. Starting a new project and choosing an avatar

• From the base of available avatars, one of the offered avatars of the female body is selected,

• Changing avatar body dimensions using the Edit Measurements option, where new body dimensions can be precisely adjusted. In this case, the body dimensions corresponding to ready-made size 38 were taken.

• The avatar is displayed in a 3D window, while its silhouette is automatically displayed in a 2D window, facilitating the construction of tailoring parts (Figure 9).

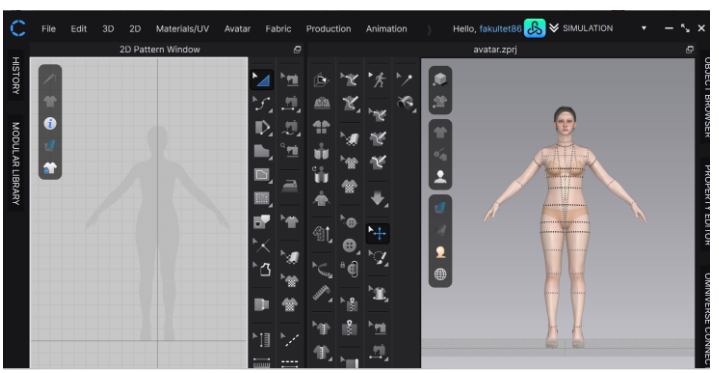
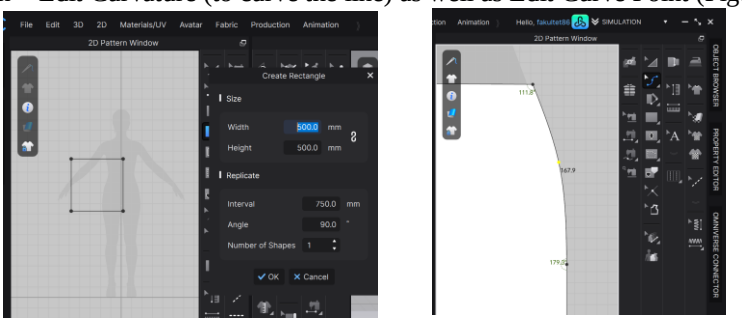


Figure 9: Avatar creation in 3D window and its shade in 2D window

2. Construction of the basic shape of the skirt

• Skirt modeling starts by drawing a rectangle in the 2D window, with dimensions: width = ½ hip circumference + allowance for comfort and height = skirt length.

• Tools are used to shape the side seam:
Edit Pattern + Edit Curvature (to curve the line) as well as Edit Curve Point (Figure 10)



a) b)

Figure 10: a) Rectangle creation, b) curvature creation

3. Dart creations

• Grommets are created using the Add Dart tool. The position and size of grommets are precisely defined numerically in the dialog window (Figure 11).

4. Placement of cutting parts

• Tailoring parts (front and back) are placed automatically with the help of the function: Auto Arrangement - which positions the parts on the avatar according to the type of garment (Figure 11).

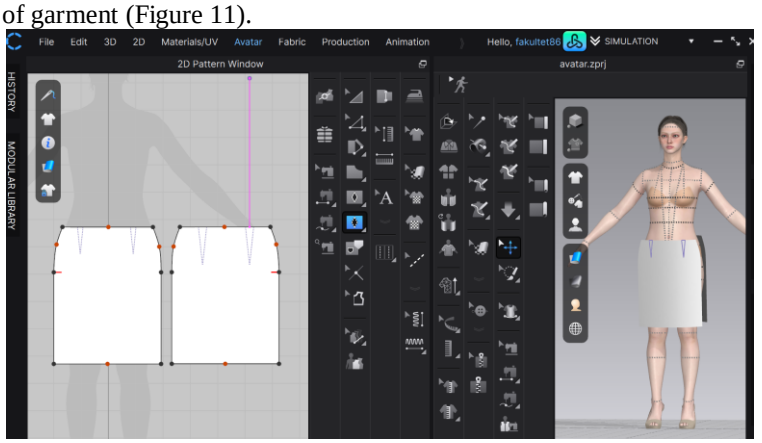


Figure 11: Dart creation in 2D window and Arrangement of cutting parts in 3D window

5. Sewing and simulation

• Joining of cut parts was done with the tool: Segment Sewing

• After all the parts were connected, a simulation was run to check the behavior of the fabric and the construction of the skirt.

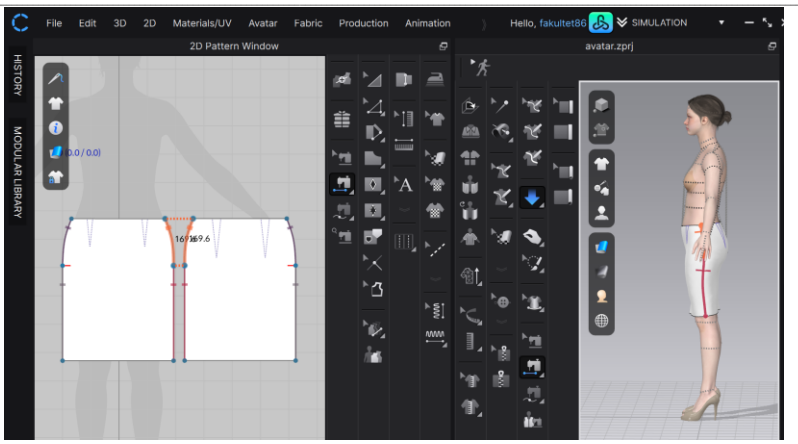


Figure 12: Sewing and simulation

6. Defining the material

• Material information (eg fabric type, thickness, elasticity, weight) is entered in the Fabric Property Editor.

• Material is dragged onto a 3D model from the library, resulting in a realistic fabric drop in virtual space.

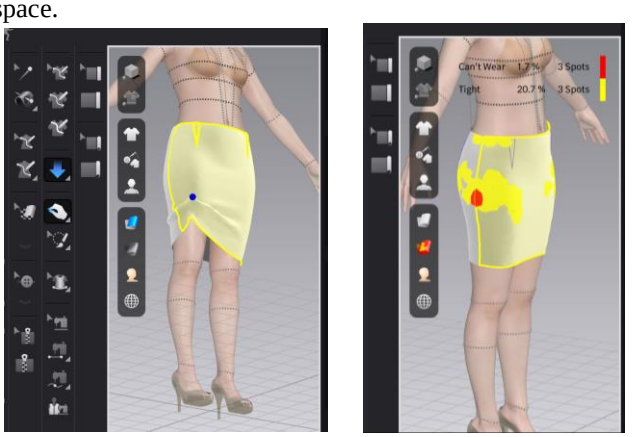


Figure 13: a) Fabric drop testing, b) strain map

7. Fit analysis

• After the simulation Fit Map and Strain map was turned on. It shows the tension of the fabric by colour and visualizes the areas where the material is under stress.

8. Modeling the straight skirt into the desired model according to the technical sketch.

• The front cutting part is duplicated first

• Using the functions Edit curve point and Edit curvature reshapes

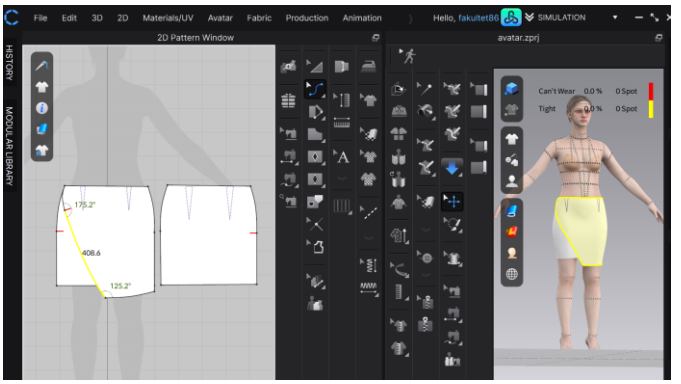


Figure 14: Final presentation of the skirt model

9. Final processing and presentation of the model (Figure 14.)

6. COMPARATIVE ANALYSIS OF MODARIS AND CLO APPROACEHS IN SKIRT DESIGN

In order to assess the effectiveness and potential of modern digital tools for constructing and visualizing clothing, a comparative analysis of the same model of a woman's skirt was carried out in two different software environments - Modaris (Lectra) and CLO 3D.

Table 2: Comparative analysis of women's skirt model creation in Modaris and CLO 3D software

	Modaris approach	CLO 3D approach
Time required for production	95 minutes (multiple steps, manual processing). Note: the time depends on the experience of the operator	45 minutes (faster development directly on the avatar). Note: the time depends on the experience of the operator
Visual inspection of the model	Limited visual assessment	Realistic 3D simulation in real time
2D cuting parts creation	Accurate, but after manual digitization	Accurate, created by drawing
Possibility of comfort testing	No integrated simulation	Simulation of material behavior, movement and falling
Size grading	Gradation is more precise and flexible, using detailed control by points, segments, multiple rules for various sizes.	CLO is not primarily intended for precise industrial grading
creating a tailoring image	The fitting in cuting pictres is precise, but requires technical knowledge and additional steps and the use of the Diamino program.	It is possible to create a "Snapshot of Pattern" and connect 2D and 3D views, but there is no professional marker system

7. CONCLUSIONS

Digital technologies in the field of clothing design and construction are a key tool for improving sustainability, efficiency and flexibility in the fashion industry. By introducing tools for 3D visualization and simulation, such as CLO 3D, it is possible to significantly reduce the need for physical prototypes, accelerate collection development and more accurately assess the behavior of materials on a virtual body.
The experimental part of the work, in which the modeling of a woman's skirt in Modaris software and the CLO 3D platform was compared, pointed out key differences in production time, visual control, adaptability and potential for virtual testing. While Modaris is still a dominant presence in domestic fashion businesses, its use remains mostly limited to 2D CAD processing. On the other hand, CLO 3D enables faster and more intuitive model creation with a realistic representation of fabric construction and behavior. The work shows that the application of 3D tools not only contributes to the improvement of the design process, but also represents an important step towards the sustainable transformation of the fashion industry. Bearing in mind the low representation of these tools in the practice of domestic companies, it is necessary to work on staff education, integration of modern software and adaptation of educational programs in order to ensure the competitiveness and innovation of the sector in accordance with global trends.

FUNDING
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CONTEMPORARY ASPECTS OF THE APPLICATION OF NATURAL DYES IN THE MULTIDISCIPLINARY PROJECT “ALL THE COLORS OF MONTENEGRO – DYEING WOOL WITH VEGETABLE DYES“

Professional paper
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ABSTRACT: *The multidisciplinary project "All colors of Montenegro - dyeing wool with vegetable dyes" combines science, tradition and art and contributes to the preservation and revival of the cultural heritage of wool as well as the use of wool in other areas such as agriculture, construction, etc. By taking up the ideas of the project, an important contribution can be made to reducing pollution and realising the principles of the circular economy, because wool that remains in nature is pollution. The use of indigenous waste or easily renewable plant sources is also insisted upon in the dyeing processes. For dyeing different plants can be used: madder root, black ash leaves, onion skins, walnut leaves. As part of the project, workshops in textile dyeing and traditional felting techniq are organised for students from various disciplines and interdisciplinary lectures are held in the fields of ethnology, philosophy and culture of fashion, biology and chemical textile technology. The focus is on pre-school education and encouraging design students to take an interdisciplinary approach to textiles.*

Keywords: *natural dyes, wool, felting, textile heritage, education, fashion design.*

SAVREMENI ASPEKTI PRIMENE PRIRODNIH BOJILA U OKVIRU MULTIDISCIPLINARNOG PROJEKTA „SVE BOJE CRNE GORE – BOJENJE VUNE BILJNIM BOJAMA“

APSTRAKT: *Multidisciplinarni projekat "Sve boje Crne Gore - bojenje vune biljnim bojama" povezuje nauku, tradiciju i umetnost i doprinosi očuvanju i oživljavanju nematerijalne tekstilne kulturne baštine, kao i korišćenje vune u drugim područjima kao što su poljoprivreda, građevinarstvo itd. Prihvatanjem ideje projekta može se dati važan doprinos smanjenju zagađenja životne sredine i ostvarivanju principa održivog razvoja u privredi, jer vuna koja se odlaže u prirodi predstavlja ekološki problem. U procesima bojenja insistira se na korištenju autohtonog otpada ili lako obnovljivih biljnih izvora. Za bojenje se mogu koristiti različite biljke: koren broća, listovi crnog jasena, ljuske luka, lišće oraha i dr. U sklopu projekta organizuju se radionice bojenja tekstila i tradicionalne tehnike oblikovanja tekstila, kao što je filcanje vune, za studente različitih disciplina, a održavaju se i interdisciplinarna predavanja iz područja etnologije, filozofije i kulture mode, biologije i hemijske tekstilne tehnologije. Fokus je na predškolskom vaspitanju i podstcanju studenata dizajna na interdisciplinarni pristup tekstilu.*

Ključne reči: *prirodne boje, vuna, filcanje, tekstilna baština, edukacija, modni dizajn.*

1. INTRODUCTION

Nowdays, a renewed interest in the use of natural dyes in textile colouring can be observed worldwide. The reason for this is the need to protect the environment and human health, as well as the increasingly frequent occurrence of allergic reactions caused by synthetic dyes. Colouring with vegetable dyes is an ecologically clean technology and the extracts of the plant pigments are obtained from renewable sources of plants from the environment [1-3]. Intuitive and plausible solutions in the application of materials available in rural households in combination with plant pigments (black ash, walnut, broc, onion, birch, quince leaf, St John's wort, sač, etc.) have, through centuries of practise, resulted in a durability of coloured material that cannot be surpassed even by modern technology [4-7]. Considering the importance and value of textile heritage and the need to preserve traditional recipes for dyeing with natural dyes, the project "All Colours of Montenegro - Dyeing Wool with Vegetable Dyes" is realised through the following activities: organisation of on-site workshops on dyeing wool with vegetable dyes using traditional textile techniques, including daily lectures; field research of the textile heritage of Montenegro and documentation of the knowledge of elderly women in the remote villages of the continental part of Montenegro through recording and taking interviews and photographs; collection of plants in the field in cooperation with the Natural History Museum of Montenegro and laboratory research in cooperation with the Faculty of Textile Technology of the University of Zagreb.

In addition, the project contributes to the preservation of the intangible textile heritage of Montenegro through the realisation of the following objectives and activities:

1. Technological procedures for dyeing wool with plant dyes in a traditional way; preservation and transfer of knowledge in the field of traditional textile techniques.
2. During the workshops, the participants dye the wool of domestic sheep of the Pramenka breed with natural dyes obtained exclusively from pigment plants from Montenegro.

3. Using the wool of domestic sheep and traditional techniques of knitting, weaving, dry and wet felting, with an innovative design approach, students and artists create objects of applied art, paintings, sculptures or installations of contemporary design using traditional materials and production techniques that are threatened with extinction.
3. Lectures in the fields of ethnology, art psychology, colour theory, chemistry, mental ecology, textile technology and botany are just as much a part of the programme as the presentation of the artistic practise of domestic and foreign artists.
The following chapters present the activities in the project through the optimization of the dyeing process in the laboratory (fig. 1), workshops for school-age children (fig. 2), and realization in the field of fashion design (fig. 3).

Figure 1: Optimization of the dyeing process in the laboratory

Figure 2: Workshops for school-age children

Figure 3: Traditional technics in fashion desing

2. SHEEP'S WOOL DYED WITH NATURAL DYES

The demands of modern life and industry strive for environmentally friendly and sustainable processes in all areas of human activity, including the textile industry. In response to this demand, natural dyes, which had fallen into obscurity at the end of the 19th century, have gained popularity as an acceptable alternative to synthetic dyes that are petroleum origin. In addition to beautiful color, the modern use of these dyes is also about exploring their multifunctional properties: skin care, antimicrobial, antifungal, elimination of unpleasant body odours, protection against harmful UV radiation, etc. These properties represent a synergy of the benefits of wool and plants [1-7].
The research covers the field of application of natural plant dyes for dyeing sheep wool, with emphasis on the contribution to human health, research on textile heritage and modern fashion industry based on the principles of a circular economy and the idea of "zero waste", i.e. the use of plant waste, weeds or invasive species [4-7].
To ensure the "eco" requirement, care must be taken to ensure that the selection of plants does not endanger their habitat, that the technological processes do not cause pollution, that the choice of chemicals does not affect the quality of the textile and that the textile material produced is safe and beneficial to human health [4-7].

3. LOOP BY LOOP, STITCH BY STITCH

The project "Loop by loop, stitch by stitch" is conceived as a process of imparting knowledge and skills through workshops in which children and young people learn

traditional handicraft techniques: knitting, embroidery, weaving and needle felting from local sheep's wool. All these skills are suitable for primary and secondary school children of both genders aged 6-17 (Figure 4).

Figure 4: "Loop by loop, stitch by stitch"

Modern technology has certainly helped to improve the quality of life for each of us, but it has also limited the ability of children and young people to interact with others and use their own hands to create.
The need to use their hands seems to be a thing of the past!
Past practice has shown that children and young people, when faced with a creative task, create small works, applied art, with great attention, concentration, dedication and imagination using simple tools and equipment - a weaving frame, needles, a bobbin and a quantity of colorful wool yarn dyed with vegetable dyes.
As well as developing fine motor skills and the invaluable tactile experience of working with wool, the joy they feel during the creative process and the resulting object helps to boost their self-confidence and self-esteem. Through the creative process of working with wool, a "fabric" is created that can be seen as a physical representation of the thought process and we then speak of "threads of thought".
The hands are a powerful tool for self-knowledge and learning about the world, and children need to be able to use them from an early age and later throughout their lives.

4. WARMERS FOR HEALTH AND BEAUTY

It is generally known that wool is much more environmentally friendly and durable than its textile counterparts. But wool also clearly has many benefits in terms of health [8].

Will we be using wool to treat more serious health conditions in the future? Who knows for sure? But with more research being published every year on the positive effects on skin and joint pain, it seems increasingly likely.
Aside from treatment, I am a firm believer in self-care and the small changes we need to make to become happier and healthier. This will continue to be first choice when it comes to comfort and warmth.
Designed neck warmers made from wool from Montenegro, are the part of the Old Fashion Collection, which also includes various wool garments (Figure 5).
They are made of rough and raw wool, but are very soothing for the joints, bones and skin of the neck. The wool is dyed with vegetable dyes from the surrounding plants: onion, ash, pomegranate, birch, madder and walnut...

Figure 5: “Old Fashion Collection"

5. CONCLUSION

The multidisciplinary project "All the Colors of Montenegro - Dyeing Wool with Plant Dyes" represents an important contribution to the revival of the use of natural dyes for dyeing wool. The contribution is visible in ecology through the use of secondary raw materials (wool and plant sources), in the field of preservation of textile heritage, education of young people, development of sustainable design, etc.
By implementing the ideas set out in the project, it is possible to make a significant contribution to reducing pollution and implementing the principle of the circular economy, as wool left in nature constitutes pollution. The dyeing processes also emphasise the use of local waste or easily renewable plant sources, such as black ash leaves, onion skins and green walnut shells. Special emphasis is placed on multidisciplinarity, i.e. the collaboration of ethnologists, technologists, designers and psychologists, which ensures a contribution in all the above-mentioned areas. The themes of the project are a particular challenge for

freelance artists and students of textile design who use knitting, wet and dry felting techniques to produce wool products enhanced with natural dyes.

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SESSION I

TEXTILES AND TEXTILE TECHNOLOGIES

ELECTROSPUN LIGNIN NANOFIBERS

Original scientific paper
DOI: 10.5937/CT_ITI25007E

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ABSTRACT: *Lignin-based nanofibers present significant potential for use in technical applications as a sustainable alternative to conventional materials. In this study, the electrospinning of lignin nanofibers was investigated. Polyacrylonitrile (PAN) and polyvinyl alcohol (PVA) were selected as carrier polymers to facilitate the electrospinning process. Lignin/polymer solutions with varying mixing ratios were electrospun under different applied voltages. The morphology of the resulting nanofibers was characterized using scanning electron microscopy (SEM). The results demonstrated the successful production of bead-free lignin nanofibers using both carrier polymers. Notably, the finest nanofibers were obtained with PAN, whereas the use of PVA enabled the incorporation of a higher lignin content (>80%) within bead-free nanofibers.*

Keywords: *Electrospinning, nanofiber, lignin, carrier polymer.*

ELEKTROPREDENA LIGNINSKA NANOVLAKNA

APSTRAKT: *Nanovlakna na bazi lignina predstavljaju značajan potencijal za upotrebu u tehničkim primenama kao održiva alternativa konvencionalnim materijalima. U ovoj studiji ispitivano je elektropredenje ligninskih nanovlakana. Poliakrilonitril (PAN) i polivinil alkohol (PVA) su odabrani kao noseći polimeri kako bi se olakšao proces elektropredenja. Rastvori lignin/polimer sa različitim odnosima mešanja su elektropredeni pod različitim primenjenim naponima. Morfologija dobijenih nanovlakana je okarakterisana pomoću skenirajuće elektronske mikroskopije (SEM). Rezultati su pokazali uspešnu proizvodnju ligninskih nanovlakana bez perli korišćenjem oba noseća polimera. Primetno je da su najfinija nanovlakna dobijena sa PAN-om, dok je upotreba PVA omogućila ugradnju većeg sadržaja lignina (>80%) unutar nanovlakana bez perli.*

Ključne reči: *Elektropredenje, nanovlakna, lignin, noseći polimer.*

1. INTRODUCTION

Electrospun nanofibers have attracted great attention in medical, energy and filtration applications in recent years, because of their specific properties such as high surface area, porosity and possible use of a wide variety of polymers. On the other hand, the use of biomass materials in the production of electrospun nanofibers has become a research focus for the production of sustainable materials. Lignin, which is the second most abundant plant-derived natural polymer after cellulose, is a class of complex polyaromatic biopolymers. The structural complexity and abundance of functional groups in lignin make it a promising precursor for the synthesis of various value-added products, such as high-performance carbon fibers, etc. [1]. It is mainly produced as a byproduct in pulp, paper and bioethanol industries [2]. Although lignin has great potential for biotechnological and industrial use due to the high carbon content, biodegradability, antioxidative activity and thermal stability, a very small portion of the lignin produced is used industrially [3].
Since lignin has a relatively low molecular weight, due to the low viscosity of the lignin solutions electrospinning of lignin yields sprays instead of nanofibers. Therefore, a carrier polymer of a higher molecular weight is generally necessary for electrospinning. In general PAN, PVA or PEO is used as carrier polymers [4]. In this study, lignin nanofibers were electrospun with PAN and PVA with different lignin-to-carrier polymer ratios and different electrospinning voltages. The morphology and fiber diameters of resulting nanofibers were discussed.

2. EXPERIMENTAL

Lignin (softwood alkali lignin, Mw ~10,000 g/mol), PVA (Mw 125,000 g/mol, Mowiol®) and N,N dimethylformamide (DMF, anhydrous, 99.8%) were purchased from Sigma Aldrich. Acrylic based pre-consumer textile wastes were used as PAN polymer precursor. Stock solutions of each polymer were prepared and the mixtures of lignin/PAN and lignin/PVA solutions were prepared in specific mixing ratios. Information on stock solution, mixture ratio and electrospinning parameters were given in Table 1. Nanofibers were produced by NS + NanoSpinner Plus (Inovenso, Türkiye) electrospinning equipment. A 10 mL syringe with a stainless-steel needle (3 cm long, 22 gauge, and flat tip) was used. Produced nanofibers were deposited on a grounded stationary rectangular metal collector covered by a piece of aluminum foil.

Table 1: Polymer solution and electrospinning parameters

Lignin		Carrier polymer			Mixing ratio, v:v (lignin:carrier)	Electrospinning parameters		
Polymer conc.,%	Solvent	Carrier polymer	Polymer conc.,%	Solvent		Voltage, kV	Distance, cm	Feeding rate, ml/h
20	DMF	PAN	20	DMF	50:50 60:40 70:30 80:20	15, 20, 25, 30	15	0.7
30	Water	PVA	10	Water	50:50 60:40	15, 20, 25, 30	15	0.7

The morphology of the resultant nanofibers was characterized using scanning electron microscopy (SEM, Thermo Scientific Apreo S). Each sample was coated with a thin film of gold using a Leica EM ACE600 ion sputtering device. Fiber diameters were determined by using Image J software using SEM images. Fifty measurements were carried out on different parts of each sample.

3. RESULTS AND DISCUSSION

Figure 1 presents the SEM images of lignin/PAN nanofibers fabricated using various lignin-to-PAN solution ratios and electrospinning voltages. Bead-free nanofibers could be obtained by the use of PAN as a carrier polymer at 50:50 and 60:40 solution mixing ratios (except 30 kV electrospinning voltage for 60:40 mixture ratio). The further increase in the ratio of lignin led to the formation of beaded fibers possibly due to the decrease in viscosity by the increase in the lignin ratio. On the other hand, it is worth noting that bead formation is not dominant, most of the fibers were smooth and bead formations were encountered locally in the structure. Therefore, the occurrence of rare bead formation is not expected to significantly hinder the applicability of high-lignin-content nanofibers in technical fields.

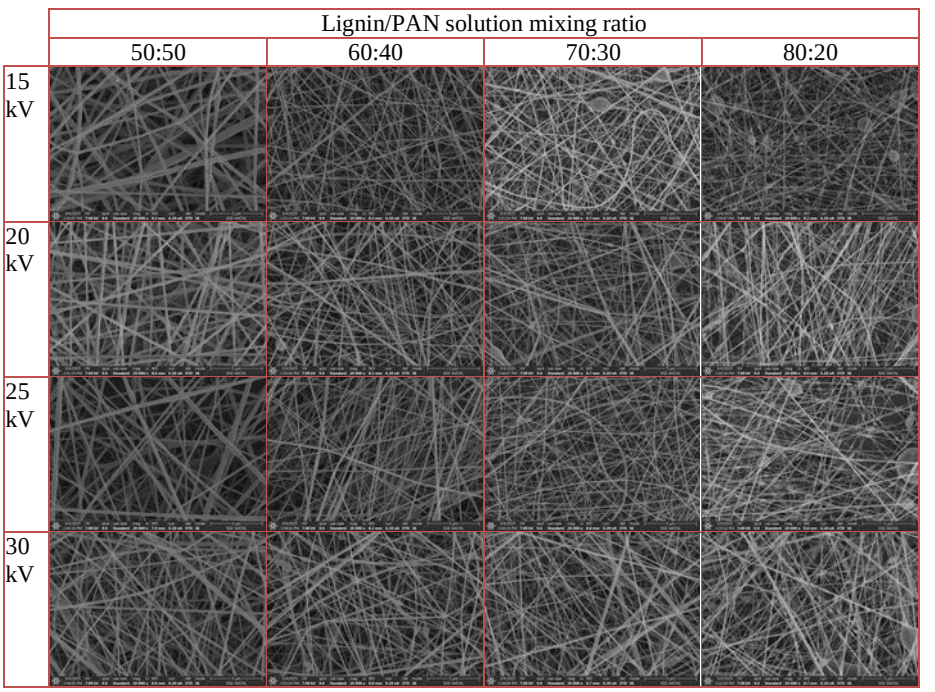

Figure 1: SEM images of lignin/PAN nanofibers

Figure 2 illustrates the SEM images of lignin/PVA nanofibers produced under different

lignin: PVA solution mixture ratios and electrospinning voltages. Only two lignin-to-PVA solution ratios could be electrospun (50:50 and 60:40), the increase in the lignin solution ratio led to an increase in viscosity which hindered polymer jet formation during electrospinning process. On the other hand, all the produced lignin/PVA nanofibers were found to be smooth and bead-free. Moreover, although the lignin:PVA solution ratio remained low in the production of nanofibers with PVA, the theoretical lignin mass ratio in the obtained nanofibers was quite high as 75% and 81%, respectively, due to the high lignin solution concentration used (30%).

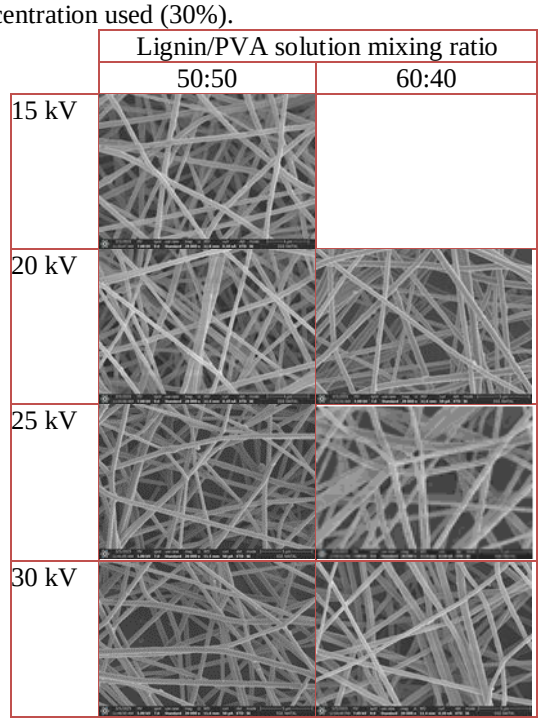

Figure 2: SEM images of lignin/PVA nanofibers

The average diameters of the fabricated nanofibers are summarized in Table 2. For lignin/PAN nanofibers, an increase in the lignin content resulted in a reduction in fiber diameter. At lower lignin ratios, higher electrospinning voltages contributed to a decrease in fiber diameter; however, this effect became negligible at higher lignin concentrations.

Table 2: Mean nanofiber diameters (nm)

	Lignin/PAN				Lignin/PVA	
	50:50	60:40	70:30	80:20	50:50	60:40
15 kV	286.8	144.2	125.7	115.0	485.5	524.6
20 kV	261.4	134.9	127.9	116.4	454.4	544.8
25 kV	254.7	135.8	126.7	113.6	420.2	495.3
30 kV	222.0	133.5	125.3	118.7	433.2	496.0

When PVA was employed as the carrier polymer, thicker nanofibers were obtained. Unlike the lignin/PAN system, increasing the lignin ratio in lignin/PVA nanofibers led to an increase in fiber diameter, because of the increase in solution viscosity. Overall, lower electrospinning voltages tended to produce thicker fibers in both polymer systems.

4. CONCLUSION

Electrospun lignin nanofibers were successfully fabricated using PAN and PVA as carrier polymers. Among the two, lignin/PAN nanofibers exhibited finer fiber morphology in comparison to lignin/PVA nanofibers. In the case of lignin/PAN systems, bead-free nanofibers were obtained at lignin contents of 50% and 60%. However, increasing the lignin content to 70% and 80% resulted in localized bead formation. Conversely, lignin/PVA nanofibers remained bead-free even at higher lignin loadings of 75% and 81%, indicating a higher compatibility of lignin with PVA for producing uniform nanofiber structures at elevated lignin concentrations.

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INVESTIGATION OF THE QUALITY OF ORGANIC WOOL DOUBLE WEFT KNITTED FABRICS

Scientific paper
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ABSTRACT: *This study investigates the quality of organic wool double weft knitted fabrics with different knit structures. Fabrics were produced in three knit structures - 1×1 rib, half Milano rib, and Milano rib - using 20×2 tex organic wool yarn. Quality evaluation was based on volume electrical resistivity, compression, and strength properties. Compression properties were evaluated through compressibility and compressive resilience, while strength properties were assessed using bursting strength and ball traverse elongation. The results indicated that the 1×1 rib structure exhibited the highest compressibility and ball traverse elongation. The Milano rib structure demonstrated the highest compressive resilience and bursting strength, whereas the half Milano rib fabric showed the lowest volume resistivity. Based on the application of the ranking method, the Milano rib fabric exhibited the best quality, while the half Milano rib structure ranked the worst quality.*

Keywords: *quality, organic wool, double weft knitted fabric, 1x1 rib, half Milano rib, Milano rib.*

ISPITIVANJE KVALITETA DESNO-DESNIH PLETENINA IZRAĐENIH OD ORGANSKE VUNE

APSTRAKT: *U ovom radu je ispitivan kvalitet desno-desnih pletenina različitog prepletaja izrađenih od organske vune. Pletenine su proizvedene u tri različita prepletaja - 1x1 prepletaj, polumilanski prepletaj i milanski prepletaj - koristeći pređu od organske vune finoće 20×2 tex. Procena kvaliteta pletenina vršena je na osnovu njihove specifične*

zapreminske električne otpornosti, kompresionih i prekidnih svojstava. Kompresiona svojstava su ocenjena na osnovu kompresibilnosti i elastičnog oporavka, a prekidna svojstava na bazi sile probijanja i hoda kugle pri probijanju. Rezultati su pokazali da pletenina u 1x1 prepletaju ispoljava najveću kompresibilnost i hod kugle pri probijanju. Pletenina u milanskom prepletaju pokazuje najveći elastični oporavak i silu probijanja, dok pletenina u polumilanskom prepletaju ispoljava najmanju specifičnu zapreminsku električnu otpornost. Na osnovu metode rangiranja, pletenina u milanskom prepletaju pokazala je najbolji kvalitet, dok je pletenina u polumilanskom prepletaju pokazala najlošiji kvalitet.

Ključne reči: *kvalitet, organska vuna, desno-desna potkina pletenina, 1x1 prepletaj, polumilanski prepletaj, milanski prepletaj.*

1. INTRODUCTION

Trends and innovations in the textile industry tend to comply with environmental requirements. In this regard, the textile industry is currently looking for ways to reduce its contribution to the total amount of microplastics that have recently been highlighted as a global problem. Microplastics can be distinguished as primary, when various particles such as synthetic fibers directly enter the environment, and secondary, when small particles are formed in situ by the breakdown of larger plastics [1]. Belzagui et al. estimated that textile washing is the most significant source of synthetic fibers released in environment, with a separation rate of 175 to 560 fibers per gram or 30000 to 465000 fibers per square meter of textile during washing [2]. Due to the size and density of synthetic fibers, it is likely that most will escape water purification processes, ending up in the oceans and potentially entering the food chain. The continuous release of synthetic fibers into the aquatic environment raises concerns about potential environmental and human health risks [3].
Therefore, in the textile industry, there is currently increasing interest in the application of natural fibers such as cotton, hemp, flax, silk, and wool. Wool has been an important fiber for textile manufactures for centuries. Although synthetic fibers were used more often than wool fibers in previous decades due to their lower cost, wool fibers were still highly valued for their exceptional properties. They are characterized by good elasticity, moisture management, heat insulation, gentle luster, etc. Wool clothing is comfortable to wear and brings many benefits such as reduced body odor, improved sleep quality, fire protection, and reduced eczema symptoms [4].
Due to the fast fashion trend, lower quality clothing, mostly made from synthetic fibers, is mass-produced and quickly loses its face value and useful life. In light of these detrimental factors, organic natural fibers have shown potential for the clothing market. The popularity of organic clothing has grown over the past decade or so, particularly due to constant changes in consumer lifestyle and increasing awareness of organic production launched by many major retailers and supermarkets. Consequently, today many consumers are willing to pay more if organic clothing offers good quality [5,6].

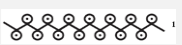
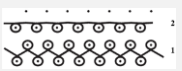
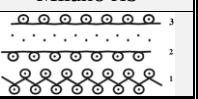
Considering the above, this study investigated the quality of three different knitted fabrics, all produced from the organic wool yarn but with the different knit structure based on rib (1x1 rib, half Milano rib, and Milano rib). The quality of these fabrics was evaluated based on their volume electrical resistivity, compressibility, compressive resilience, bursting strength and ball traverse elongation. The results obtained in this study could help the manufacturers, suppliers, and users to choose one of the tested organic wool knitted fabrics whose rib structure provides the best quality.

2. MATERIALS AND METHODS

2.1. Materials

In this study, the experimental materials consisted of double weft knitted fabrics in 1x1 rib, half Milano rib, and Milano rib structures, all made from 100% organic wool yarn (20x2 tex). The knitted fabrics were produced using a CMS 340.6L double-needle flat-bed knitting machine (Stoll, Germany) with an E12 gauge, 863 needles per needle bed, and 4 knitting systems. Throughout the production process, the stitch cam position, yarn input tension, and fabric take-down settings were kept constant. Table 1 presents the basic structural characteristics of the knitted fabrics, while Figure 1 displays their surface appearance.

Table 1: Structural characteristics of the investigated knitted fabrics

Structural characteristics	Type of knit structure		
	1x1 rib	Half Milano rib	Milano rib
			
Wales per centimeter, cm^{-1}	12.80	13.50	13.70
Course per centimeter, cm^{-1}	10.60	12.05/6.48*	10.56
Mass per unit area, $g \cdot m^{-2}$	255.9	247.7	277.7
Thickness, mm	1.220	1.042	1.227
Total porosity, %	84.11	81.99	82.85
*Knitted fabric has a different face and back side, and consequently different course per centimeter on the face and back side of fabric.			

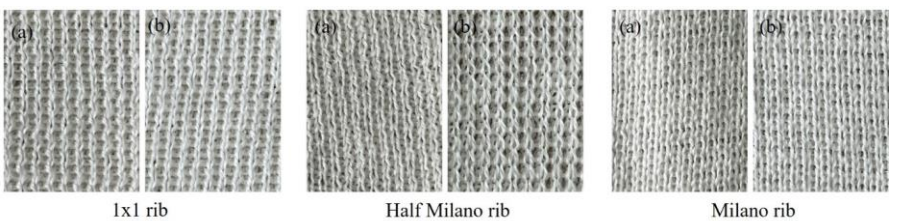


Figure 1: The surface appearance of organic wool double weft knitted fabrics in 1x1 rib, half Milano rib, and Milano rib at 10× magnification: (a) face side of fabric, (b) back side of fabric

2.2. Methods

Wales per centimeter and course per centimeter were determined following standard EN 14971:2006 (Method B) [7]. Knitted fabric mass per unit area was determined following standard EN 12127:1997 [8], while fabric thickness was measured at a pressure of 9.96 kPa using a thickness tester AMES, type 414-10, USA. The wales per centimeter, course per centimeter, mass per unit area, and thickness were considered as the average of five measurements per sample. The total porosity of the samples, representing the overall volume of air contained within them, was defined by Asanovic et al. [9].

The volume electrical resistance of the investigated knitted fabrics was determined in the course direction using the voltage method [10,11]. The measurement was performed under the decrease of the relative air humidity in the chamber from 65% down to 45%. For each sample four fabric specimens were connected to electrodes. Based on the determined knitted fabric volume electrical resistance, the volume electrical resistivity was calculated [10,11].

A thickness tester (AMES, type 414-10, USA) was used for the investigation of knitted fabrics' compression properties (compressibility and compressive resilience). The compression properties were determined according to the procedure described by Asanovic et al. [12,13]. The reported results are the mean values of five measurements per sample.

Determination of knitted fabrics' strength properties (bursting strength and ball traverse elongation) were realized using the device mounted in clamps of the dynamometer AVK, SZ type KG-2, Hungary [13]. The reported strength properties are the mean values of five measurements per sample.

Statistical analysis of the results was conducted using the *t*–test [12,13].

The quality of tested knitted fabrics was assessed based on the results obtained for fabrics' volume electrical resistivity, compressibility, compressive resilience, bursting strength and ball traverse elongation, using the ranking method (details given in the references [11].

3. RESULTS AND DISCUSSION

3.1. Volume electrical resistivity of the knitted fabrics

The values of volume electrical resistivity (in further text resistivity) in the course direction of organic wool double weft knitted fabrics in three knit structures - 1×1 rib, half Milano rib, and Milano rib, determined by decreasing the relative air humidity (in further text humidity) in the chamber, are shown in Figure 2.

The results presented in Figure 2 indicate that as humidity decreases from 65% down to 45%, the resistivity of the samples gradually increases. This confirms that the resistivity of textile materials is highly dependent on humidity, consistent with findings reported in the existing literature [14-16]. At lower humidity levels, fibers absorb less moisture, leading to decreased electrical conductivity and, consequently, increased resistivity in the tested samples. The greatest increase in resistivity was observed in the half Milano rib fabric, where the resistivity at 45% humidity was 2.58 times higher than at 65% humidity. In comparison, 1x1 rib fabric and Milano rib fabric exhibited similar increases in resistivity, with values at 45% humidity being 2.08 and 2.04 times higher, respectively, than those at

65% humidity. Across all humidity levels, the half Milano rib fabric consistently showed the lowest resistivity, while the 1x1 rib fabric exhibited the highest.

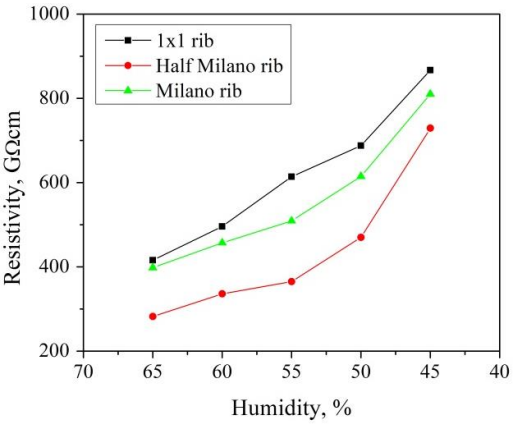


Figure 2: Resistivity of the samples throughout the humidity decrease

Since all the knitted fabrics were produced from the same organic wool yarn, these differences in resistivity are attributed to variations in the type of knit structure. The half Milano rib fabric, with the highest number of courses, and the lowest total porosity (12.05 cm^{-1}, 81.99%, respectively, Table 1) allows the easier flow of directional movement of charge, resulting in lower resistivity. This finding is in line with the investigation of Asfand end Daukantiene [17]. The slightly lower resistivity values of the Milano rib fabric, compared to the 1x 1 rib fabric, considering that both knitted fabrics have nearly identical number of courses (10.60 and 10.56 cm^{-1}, respectively, Table 1), can be attributed to greater thickness and mass per unit area, as well as lower total porosity of Milano rib fabric.

3.2. Compression properties of the knitted fabrics

In addition to resistivity, compression properties are also important properties of textile materials intended for clothing purposes. The compression properties (compressibility and compression resilience) of organic wool double weft knitted fabrics in three knit structures - 1×1 rib, half Milano rib, and Milano rib, are presented in Figure 3.

The results shown in Figure 3(a) indicate that the 1x1 rib fabric exhibits the highest compressibility, while the half Milano rib fabric shows the lowest. Specifically, the 1x1 rib fabric has 19.3% greater compressibility than the half Milano rib fabric. This is attributed to the lower stitch density and higher total porosity of the 1x1 rib fabric (Table 1), which creates a more open knit structure. This openness allows the yarns to flatten more easily under compressive force, thereby enhancing compressibility. In contrast, the half Milano rib fabric, with the lowest porosity (Table 1), has a more compact knit structure that limits yarn flattening under pressure, resulting in reduced compressibility [13,18]. Statistical analysis using a *t*-test (Table 2) confirms that the differences in compressibility among all tested knitted fabrics are statistically significant.

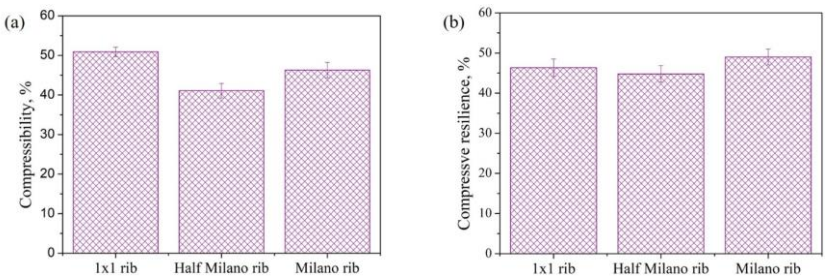


Figure 3: Compression properties of knitted fabrics: (a) compressibility, (b) compressive resilience

According to Taylor and Pollet [19], fabrics that compress more easily under a compressive load are generally perceived as softer. In this regard, the 1x1 rib fabric, which demonstrated the highest compressibility, can be considered the softest among the tested samples.

Table 2: Statistical results of the determination of knitted fabric compression properties using *t*-test

Tested parameter	Values of parameter *t* based on type of knit structure ($df=n_1+n_2-2=8$)		
	$t_{(1x1\ rib)/(half\ Milano\ rib)}$	$t_{(1x1\ rib)/(Milano\ rib)}$	$t_{(half\ Milanorib)/(Milano\ rib)}$
Compressibility	10.01 (***)	4.54 (**)	-4.35 (**)
Compressive resilience	1.15 (/)	-2.05 (/)	-3.35 (*)
(*) – 0.05 level of significance, (**) – 0.01 level of significance, (***) – 0.001 level of significance, (/) – no statistically significant difference, *df* – degrees of freedom, *n* – sample size			

In addition to softness, it is essential for knitted fabrics to exhibit good recovery after compression, a property that can be evaluated by measuring their compressive resilience [13]. The results presented in Figure 3(b) show that the Milano rib fabric has the highest compressive resilience, followed by the 1x1 rib fabric, while the half Milano rib fabric exhibits the lowest values of compressive resilience. During compression of the knitted fabrics, yarns are pressed closer together, increasing the tension between loops. This tension is greatest in the Milano rib fabric, due to the highest values of the mass per unit area and thickness among the samples. Upon decompression, the loops tend to return to their relaxed state. The greater loop tension in the Milano rib fabric facilitates a more effective return to this state, resulting in higher compressive resilience. Statistical analysis (Table 2) confirms a statistically significant difference in compressive resilience only between the half Milano rib and Milano rib fabrics ($t_{(half\ Milano\ rib)/(Milano\ rib)} = -3.35$).

3.3. Strength properties of the knitted fabrics

The results of tested strength properties (bursting strength and ball traverse elongation) for organic wool double weft knitted fabrics in three knit structures - 1×1 rib, half Milano rib, and Milano rib, are shown in Figure 4.

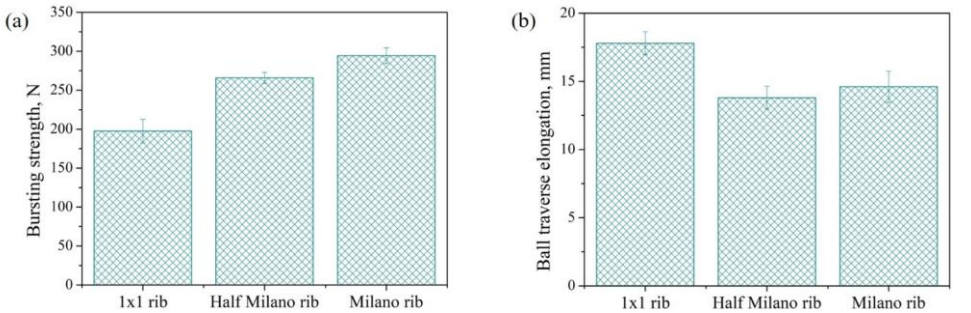


Figure 4: Strength properties of knitted fabrics: (a) bursting strength, (b) ball traverse elongation

The histogram in Figure 4(a) shows a clear upward trend in bursting strength across the knitted fabrics, increasing from the 1x1 rib fabric, through the half Milano rib fabric, to the Milano rib fabric. The superior bursting strength of the Milano rib fabric can be attributed to its higher mass per unit area and thickness (Table 1). These structural characteristics enhance the frictional forces between the yarns, increasing resistance to the ball's penetration. Statistical analysis using a *t*-test (Table 3) confirms a statistically significant difference in bursting strength among all the tested knitted fabrics at a 0.001 significance level.

Table 3: Statistical results of the determination of knitted fabric strength properties using *t*-test

Tested parameter	Values of parameter *t* based on type of knit structure ($df=n_1+n_2-2=8$)		
	$t_{(1x1\ rib)/(half\ Milano\ rib)}$	$t_{(1x1\ rib)/(Milano\ rib)}$	$t_{(half\ Milano\ rib)/(Milano\ rib)}$
Bursting strength	-9.19(***)	-11.94(***)	-5.16(***)
Ball traverse elongation	7.53(***)	5.06(***)	-1.26(/)
(***) – 0.001 level of significance, (/) – no statistically significant difference, *df* – degrees of freedom, *n* – sample size			

The results presented in Figure 4(b) indicate that the 1x1 rib fabric exhibits the highest ball traverse elongation, while the half Milano rib fabric shows the lowest. The 1x1 rib fabric demonstrated a 22.5% greater ball traverse elongation compared to the half Milano rib fabric, which can be attributed to its higher total porosity (Table 1). This increased porosity reduces the frictional forces between yarns, allowing the ball to travel farther before the fabric structure fails. Statistical analysis (Table 3) shows no statistically significant difference in ball traverse elongation only between the half Milano rib and Milano rib fabrics ($t_{(half\ Milano\ rib)/(Milano\ rib)}$ = -1.26), probably due to the they closely total porosity values (Table 1). Figure 5 displays the surface appearance of the tested fabrics following the evaluation of their strength properties.

Figure 5: The surface appearance of organic wool double weft knitted fabrics in three knit structures - 1×1 rib, half Milano rib, and Milano rib, at 10 × magnifications following the evaluation of their strength properties

Figure 5 illustrates that the indentation left by the ball after piercing is more prominent in the half Milano rib and Milano rib fabrics, i.e. samples characterized by lower porosity (Table 1).

3.4. Quality of knitted fabrics

The average quality score for each sample was used to determine the ranking of the tested knitted fabrics in terms of quality (Table 4).

Table 4: The rank order of knitted fabrics

Type of knit structure	G_1	G_2	G_3	G_4	G_5	G_{av}	Rank of fabric
1x1 rib	3	1	2	3	1	2.0	II
Half Milano rib	1	3	3	2	3	2.4	III
Milano rib	2	2	1	1	2	1.6	I

G_1 — grade of resistivity, G_2 — grade of compressibility, G_3 — grade of compressive resilience, G_4 — grade of bursting strength, G_5 — grade of ball traverse elongation, G_{av}—average value of grades (Grade “1” indicates the best and grade “3” indicates the poorest analyzed properties).

Based on the evaluated properties, the results in Table 4 indicate that the Milano rib fabric exhibits the best quality (average grade value of 1.6 – Rank I), while the half Milano rib fabric demonstrates the worst quality (average grade value of 2.4 – Rank III).

4. CONCLUSION

The findings of this study showed that the type of knit structure influence the quality of organic wool knitted fabrics. The investigation revealed that the 1x1 rib fabric has the highest compressibility (50.92 %) and ball traverse elongation (17.80 mm), that the Milano rib fabric has the highest compressive resilience (49.02 %) and bursting strength (294.30 N), and that the half Milano rib fabric has the lowest volume resistivity (from 282 to 729 GΩcm in humidity interval from 65% to 45%, respectively). Quality analysis determined

based on the ranking method (including volume electrical resistivity, compressibility, compressive resilience, bursting strength and ball traverse elongation) showed that the Milano rib fabric has the best quality, and that the half Milano rib fabric has the worst quality. The findings of this study could help manufacturers, suppliers, and users to select one of the tested organic wool knitted fabrics whose the type of knit structure provides the best quality.

ACKNOWLEDGEMENT
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WAFFLE FABRIC DESIGN WITH DIFFERENT WEAVE CONSTRUCTIONS

Review scientific paper
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ABSTRACT: *This study presents a design collection that reinterprets the traditional waffle weave texture, offering both a visual and tactile narrative. The raised structures on the fabric's surface form a silent language—conveying sensations of relaxation, refreshment, and memory through texture rather than words. In this approach, texture becomes not merely a structural element, but a communicative stance and an intentional design choice. The surface is crafted for those who express through touch rather than speech—leaving a lasting impression on everyone who interacts with it.*
Within this conceptual framework, seven original waffle weave patterns were developed. The technical settings and constructions for each pattern were defined, and samples were produced using both dobby and jacquard weaving machines. For the warp and ground yarns, Ne 20/2 ring combed cotton was used; Ne 10/1 open-end cotton yarns were employed for the weft. The woven fabrics were then transformed into finished bathrobe products, enabling the designs to be experienced functionally as well as aesthetically.
The different waffle weave patterns yielded fabrics with varied visual and tactile properties. These designs were comparatively evaluated, particularly in relation to moisture absorption, humidity response, and overall fabric behavior—factors that are crucial in bathrobe textiles.

Keywords: *Woven design, waffle weave, terry fabric, bathrobe, textile design.*

VAFLASTI DIZAJN TKANINE SA RAZLIČITIM KONSTRUKCIJAMA TKANJA

APSTRAKT: *Ova studija predstavlja dizajnersku kolekciju koja reinterpretira tradicionalnu teksturu vafl tkanja, nudeći i vizuelnu i taktilnu naraciju. Istaknute strukture na površini tkanine formiraju tihi jezik – prenoseći osećaje opuštanja, osveženja i sećanja kroz teksturu, a ne rečima. U ovom pristupu, tekstura postaje ne samo strukturni element,*

već komunikativni stav i namerni dizajnerski izbor. Površina je izrađena za one koji se izražavaju dodirom, a ne govorom – ostavljajući trajan utisak na svakoga ko sa njom interaguje.
U okviru ovog konceptualnog okvira, razvijeno je sedam originalnih uzoraka vafl tkanja. Definisane su tehničke postavke i konstrukcije za svaki uzorak, a uzorci su proizvedeni korišćenjem mašina za tkanje dobi i žakard mašina. Za osnovu i donju pređu korišćen je prstenasto češljani pamuk Ne 20/2; za potku su korišćene pamučne pređe otvorenih krajeva Ne 10/1. Tkane tkanine su zatim transformisane u gotove proizvode za kupaće ogrtače, omogućavajući da se dizajni dožive i funkcionalno i estetski.
Različiti uzorci vafl tkanja dali su tkanine sa različitim vizuelnim i taktilnim svojstvima. Ovi dizajni su uporedno procenjeni, posebno u odnosu na apsorpciju vlage, reakciju na vlagu i ukupno ponašanje tkanine – faktore koji su ključni kod tekstila za ogrtače.

***Ključne reči**: Tkani dizajn, vaflasto tkanje, frotir, ogrtač, dizajn tekstila.*

1. INTRODUCTION

Woven fabrics are among the most widely used textile structures, offering versatility in texture, durability, and design [1]. As the interplay of yarn type, weave pattern, and finishing techniques determines both functional and aesthetic properties, the field of textile design continues to evolve through experimental and sensory-focused approaches. In particular, terry and waffle weaves hold significant importance in personal care textiles due to their tactile richness and moisture absorption capacity.
Terry fabrics are characterized by their looped pile, which enhances water absorbency and softness—making them ideal for towels and bathrobes [2]. Meanwhile, waffle weaves, also referred to as honeycomb or cellular structures, are distinguished by their three-dimensional grid-like texture, providing a unique combination of absorbency, breathability, and lightweight feel [3]. This structure not only enhances functionality but also offers a distinct visual and tactile identity, often sought after in luxury bath textiles.
Bathrobes, as end-use products, integrate comfort, functionality, and emotional appeal, and are often associated with relaxation and daily rituals of self-care. The tactile features of bathrobe fabrics contribute not only to physical comfort but also to sensory experience, a concept increasingly emphasized in contemporary textile design [4]. The evolution of textile design has moved beyond functionality, incorporating emotional and psychological dimensions, where texture becomes a language in itself [5].
In recent years, textile designers have explored waffle weaves not just for their absorbency, but also as a medium for expressive surface design. The structural variability in waffle weave construction allows for the creation of visually and texturally diverse surfaces, suitable for creative reinterpretation [6]. Within this context, the present study aims to reimagine traditional waffle fabric design by developing new weave patterns intended for bathrobe production. Through the integration of design thinking, weaving technology, and material experimentation, this research proposes a tactile design language that extends beyond conventional textile functionality.

2. MATERIALS AND METHODS

In this study, seven distinct waffle weave structures were designed with the aim of exploring new tactile and visual qualities in bathrobe textiles. The design process began with the development of unique weave patterns using textile CAD software. Each design was conceptualized to produce a different three-dimensional surface expression while preserving the absorbency and functionality characteristic of waffle fabrics.
For the production of samples, two different weaving technologies were employed: dobby and jacquard weaving machines. Dobbu fabrices were woven on a Staubli-brand dobby loom, and jacquard fabrics were woven using a Staubli-brand electronic jacquard loom. These platforms were selected to accommodate both simple and complex weave patterns.
The following materials were used in the production process:
- Ground warp yarns: Ne 20/2 100% cotton ring combed yarns
- Ground weft yarns: Ne 10/1 100% cotton open-end yarns
- Pile yarns Ne 20/2 100% cotton ring combed yarns
The yarns were selected for their softness, moisture absorption capacity, and compatibility with terry and waffle weave structures. The ground and binding yarns for all patterns consisted of Ne 20/2 combed cotton, ensuring uniformity and structural integrity across different samples. The weft yarn, Ne 10/1 open-end cotton, contributed to the bulky texture and enhanced tactile performance of the fabric.
The weaving parameters were as follows:
- Warp density: 25 ends/cm
-Weft density: 26 picks/cm
- Weightiness: 1st Design-430 g/m²; 2nd Design 425 g/m²; 3rd Design 380 g/m²; 4th Design 395 g/m²; 5th Design 405 g/m²; 6th Design 425 g/m²; 7th Design 415 g/m²
Each weave structure was woven under controlled settings to ensure consistency in tension, density, and weave fidelity. After weaving, the fabrics were subjected to standard wet finishing processes, including washing and drying, to simulate real-life use and to stabilize the fabric geometry.
Subsequently, the woven fabrics were cut and sewn into bathrobe prototypes. This allowed the evaluation of design performance not only on flat fabric samples but also in finished product form, emphasizing the transformation of woven design into functional and emotional user experiences.
The produced fabrics were evaluated comparatively based on their visual aesthetics, surface texture, and potential tactile appeal. Although quantitative testing (e.g., absorption rate or air permeability) was not the focus of this phase, qualitative observation and user interaction feedback guided the analysis of design effectiveness.

3. RESULTS AND DISCUSSION

This study resulted in the development of seven original waffle weave designs, each created with the intention of offering distinct tactile and visual experiences within the context of bathrobe textiles. The constructional details, woven fabric appearances, and final bathrobe

forms of each design are presented in the figures below [Figures 1–7]. These visuals illustrate the transformation of design concepts from theoretical weave structures into functional textile products.

Each weave pattern was carefully developed to alter the depth, repetition, and geometric flow of the waffle texture. While maintaining the fundamental three-dimensional grid structure characteristic of waffle weaves, variations were introduced through different interlacing sequences and binding points. These differences are clearly visible in the weave construction diagrams, where systematic changes in yarn path and float length contribute to the distinct surface characteristics of each design.

The woven fabric samples exhibited a wide range of surface behaviors, from subtle, shallow reliefs to deep, cellular textures. These structural nuances not only influenced the fabric's aesthetic appeal but also its tactile response. For example, designs with larger waffle cells and longer floats resulted in softer and more cushion-like surfaces, while tighter and more compact patterns offered a firmer and more resilient hand feel.

Figure 1: 1st waffle design

Figure 2: 2nd waffle design

Figure 3: 3rd waffle design

Figure 4: 4th waffle design

Figure 5: 5th waffle design

Figure 6: 6th waffle design

Figure 7: 7th waffle design

When transformed into bathrobe prototypes, the impact of each design became even more pronounced. The final product views highlight how structural design decisions affect the drape, volume, and perceived comfort of the garments. Some designs contributed to a more luxurious and enveloping silhouette, while others supported a lightweight and breathable user experience—an increasingly important factor in modern loungewear preferences.

The variety of structures offered by the seven weave patterns demonstrates the creative and functional potential of waffle weaves beyond their traditional use. In recent years, consumer interest in waffle-textured fabrics has grown due to their moisture management, thermal comfort, and minimalistic aesthetic. This research contributes to that trend by proposing innovative surface designs that can cater to both performance expectations and sensory engagement.

In addition, the study reinforces the idea that textile design is not merely a technical process, but also an emotional and experiential one. The possibility to communicate comfort, softness, and personal ritual through texture aligns with contemporary approaches in sensorial and user-centered design. Thus, the newly developed patterns are not only structurally distinct but also emotionally resonant for users seeking tactile connection in everyday garments.

4. CONCLUSION

This study explored the expressive and functional potential of waffle weave structures in the context of bathrobe design, resulting in the development of seven original woven patterns. By reinterpreting the conventional waffle texture through creative design and thoughtful construction, the research demonstrated how surface structure can serve not only as a functional textile feature but also as a medium of tactile and emotional communication. Each pattern introduced a unique interaction between visual geometry and fabric behavior, contributing to a broader spectrum of user experiences—from comfort and absorbency to softness and aesthetic appeal. The transformation of these fabrics into finished bathrobes further illustrated the real-world application and impact of surface-level design decisions on garment performance and user satisfaction.

As waffle fabrics continue to gain popularity in modern textile markets due to their minimal design language, breathability, and sensory qualities, this study contributes valuable design alternatives that respond to evolving user preferences. By integrating weaving technology with user-centered design thinking, the developed patterns offer both innovative aesthetics and enhanced functional performance.

In conclusion, this research affirms the role of textile designers not only as technical problem-solvers but also as creators of meaningful, multisensory experiences. The outcomes of this study provide a foundation for further explorations into sensorial textile design, and open new directions for design-driven innovations in the field of personal comfort textiles.

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INFLUENCE OF YARN STRUCTURE ON LIQUID TRANSFER PROPERTIES OF PLAIN KNITTED FABRICS

Review scientific paper
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ABSTRACT: *Liquid transport is one of the most significant comfort-related properties of textile fabrics intended for underwear and sportswear. To meet the wearer's thermophysiological comfort, the textile fabric has to transmit and release sweat away from the skin. The fabric's capability to transmit liquid sweat is affected by various factors, including the structure of the yarn it is made from. Due to the limited results available in the literature regarding the influence of yarn twist on the "liquid permeability" of textile fabrics, this research aimed to investigate the effect of yarn twist on liquid transfer through plain knitted fabrics. Additionally, the influence of moisture content in the fabric on the liquid transport was investigated. Three plain weft knitted fabrics were produced from three cotton yarns differing in twist. These knitted fabrics were subjected to the Malden Mills water distribution test, with some modifications. The liquid transfer properties of the knitted fabrics were evaluated using parameters - water transfer ability and water holding capacity. The results obtained indicated that varying the yarn twists, which directly influence the geometry and distribution of the complex pore system in knitted fabrics, allows for effective design of the liquid transfer properties.*

Keywords: *yarn, twist, knitted fabric, water transfer ability, water holding capacity.*

UTICAJ STRUKTURE PREĐE NA PRENOS TEČNOSTI KOD GLATKIH PLETENINA

APSTRAKT: *Sposobnost prenosa tečnosti predstavlja jedno od najznačajnijih svojstava komfora tekstilnih materijala namenjenih za izradu rublja i sportske odeće. Kako bi se obezbedio termofiziološki komfor osobi koja nosi određeni odevni predmet, tekstilni materijal treba da omogući nesmetani prenos i oslobađanje znoja sa površine kože. Sposobnost tekstilnog materijala da prenosi tečni znoj uslovljena je nizom faktora uključujući strukturu pređe od koje je materijal proizveden. Kako je u naučnoj literaturi prisutan ograničen broj rezultata koji se odnose na uticaj upredenosti pređe na propustljivost tečnosti kod tekstilnih materijala, cilj ovog istraživanja bio je ispitivanje uticaja upredenosti pređe na prenos tečnosti kroz glatke DL pletenine. Pored toga, ispitivan je uticaj sadržaja vlage u materijalu na sposobnost prenosa tečnosti. Tri različito upredene*

pamučne pređe upotrebljene su za izradu tri glatke DL pletenine. Ove pletenine su podvrgnute Mallden Mills-ovom testu distribucije vode, uz određene modifikacije. Svojstva upravljanja tečnošću ovih pletenina ocenjena su pomoću parametara – sposobnost prenosa tečnosti i sposobnost zadržavanja tečnosti. Dobijeni rezultati su pokazali da se variranjem upredenosti pređe, čime se direktno utiče na geometriju i distribuciju kompleksnog sistema pora u pletenini, omogućuje efikasno projektovanje svojstava upravljanja tečnošću pletenine.

Ključne reči: *pređa, upredenost, pletenina, sposobnost prenosa vode, sposobnost zadržavanja vode.*

1. INTRODUCTION

The ability of the textile material to transfer heat and to allow air and water vapor to pass through is essential for achieving optimal thermal comfort. However, liquid sweat forms on the skin surface during intense physical activities or frequent changes in environmental conditions. If liquid sweat is not promptly removed from the skin surface, it can impair the feeling of comfort. Therefore, the ability of the textile material to transfer liquid and allow the evaporation of sweat becomes the fourth important factor of thermal comfort in dynamic conditions. Previous research has indicated a significant effect of yarn structure and properties on the moisture management ability of plain knitted fabrics [1-5]. Only a few studies address the impact of yarn twist on "liquid permeability" [6-8]. Therefore, in this investigation, an attempt was made to indicate the influence of yarn twist on the liquid transfer properties of plain knitted fabrics. In addition, a step forward has been taken by considering the effect of moisture content in the fabrics on their liquid transfer properties.

2. MATERIALS AND METHODS

Three cotton yarns, all having the same linear density 50 tex and different twist levels (490, 590, and 690 t/m), were used to produce three plain weft knitted fabrics. They were produced under controlled conditions on a circular knitting machine and wet relaxed to relax their structure. The characteristics of the weft relaxed plain knitted fabrics are presented in Table 1. These knitted fabrics were subjected to the Malden Mills water distribution test (Polartec® LLC, USA) [9], with some modifications. A square knitted fabric sample was placed on the absorbent side of a filter paper. After 1.5 ml of water was dripped uniformly over the sample surface, and left for 2 min to stabilize, the sample was covered by another filter paper and a piece of Plexiglas, then the paper-sample-paper sandwich was weighted down with a 500 g weight. The weight was removed after 1 minute, and the masses of the partially moistened filter papers were recorded. The difference between the masses of the wet and dry lower filter paper indicated the mass of water absorbed by the paper, or water transferred through the knitted sample. The ratio of the transferred water mass to the total water absorbed by both filter papers indicates the water transfer ability of the fabric. The water holding capacity of the knitted fabrics was

calculated by subtracting the total mass of water absorbed by both filter papers from the total mass of water applied to the sample.

Table 1: Construction characteristics of the wet relaxed knitted fabrics

Parameter, unit		KCo1	KCo2	KCo3
Stitch density	Wale, cm^{-1}	6.9	6.8	7.1
	Course, cm^{-1}	12.0	12.5	12.0
	Surface, cm^{-2}	82.8	85.0	85.5
Thickness, mm		1.248	1.256	1.268
Areal density, g/m^2		446.2	453.0	458.4
Bulk density, g/m^3		0.358	0.361	0.362
Porosity, %		76.2	76.0	75.9

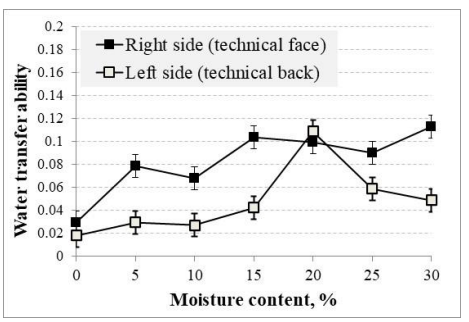
The fabric samples were tested with both the left (technical back) and right (technical face) sides facing up (in contact with water), and the parameters: water transfer ability and water holding capacity were determined for both sides in contact with water.
This study conducted a modified Malden Mills water distribution test while varying the moisture content in the knitted fabrics in 5% increments, starting from 30% down to 0% (ultra-dry state). The various levels of sample wetness were achieved using the moisture analyser (Radwag MA 50.R). The water distribution test was conducted in triplicate on both sides of the fabrics and at each moisture content level.

2. RESULTS AND DISCUSSION

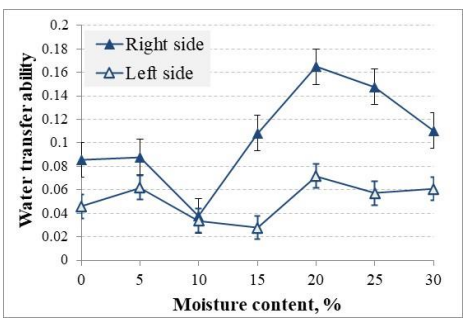
As a result of the different twists of the cotton yarns, the fibre packing density in these yarns is not the same. The lowest fibre packing density is expected for the least twisted cotton yarn, while the highest fibre packing density of the most twisted yarn is anticipated. Data on the structural and geometric characteristics of the plain knitted fabrics produced from differently twisted cotton yarns (Table 1) indicate their almost identical structures. The discrete differences in the stitch density in these three knits are due to the different flexibility of the cotton yarns. The differences in the flexibility of cotton yarns are caused by their different twists. As the twisting intensity increases, the pressure on the fibre layers in the yarn increases, which increases the frictional forces between the fibres and decreases their mobility. As shown in Table 1, the knit made from medium-twisted cotton yarn (KCo2) exhibits a slightly higher course density, whereas the knit made from the highest twisted yarn (KCo3) displays a somewhat higher wale density. As a result, the stitch surface density of these two knits is almost identical, while the stitch surface density of the knit made from the least twisted cotton yarn (KCo1) is slightly lower. The observed differences, although small, indicate certain differences in the loop configuration in these three knits. The order of knits, starting from the one with the highest surface mass (KCo3), to the knit with the lowest surface mass value (KCo1), is in accordance with their surface density (Table 1). The same order of knits is also observed regarding thickness (KCo3>KCo2> KCo1). Considering geometrical properties, knitted fabrics are characterized by the same density and porosity (Table 1).

2.1. Water transfer ability

The equilibrium moisture content of the tested knits was 5.3%, 4.9%, and 4.2% for KCo1, KCo2, and KCo3, respectively. The amount of moisture above the equilibrium moisture content will either be absorbed by the fibres or fill the knit pores. Water transfers through a textile fabric transversally and radially in the Malden Mills water distribution test. Initially, water transfers through macropores outward as the liquid spreads along the path of least resistance. After macropores become saturated, they serve as reservoirs for micropores to wick the water [10]. When analysing the results obtained, the hydrophilic nature of cotton fibres should be taken into account, i.e., the increased affinity of cotton fibres for absorbing water. The experimental results are shown in Figure 1. Considering some previous results [3], it can be said that the knitted fabrics tested exhibited a relatively low ability to transfer liquid. This can be explained by the relatively high stitch density of the knitted fabrics, indicating relatively small macropore size. The graph in Figure 1a shows two zones of water transfer ability of KCo1 knit. In the first zone (up to 10% moisture content), a lower liquid transfer capacity is observed with a slight improving trend with an increase in moisture content up to 30%. With more moisture content, except moisture absorbed by the fibres, some liquid partially fills the macropores. The swelling of the fibres, with the partial closure of the macropores, accelerates the transfer of the liquid. The same trend can be noted regardless of which side, the right (technical face) or left (technical back) of KCo1 knit is in contact with water. However, the ability of this knit to liquid transfer is greater in the direction from the face to the back of the knit (right to left). This can be explained by the specifics of plain knitted fabrics in which all loops exhibit a technical back side, while on the technical face side, only the right sides of the loops (loop legs) are on view. A smoother right-side surface of the knit will wet more quickly, allowing for faster liquid transfer through the knit.



a)



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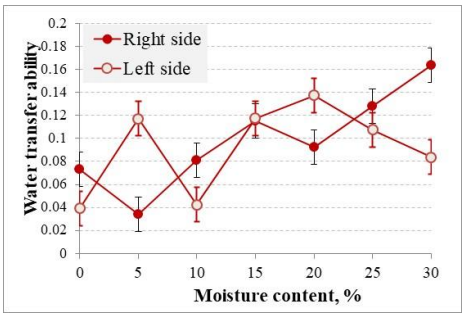
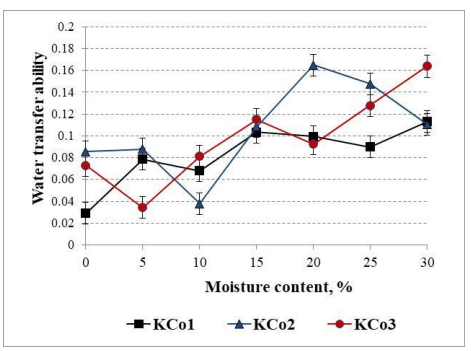


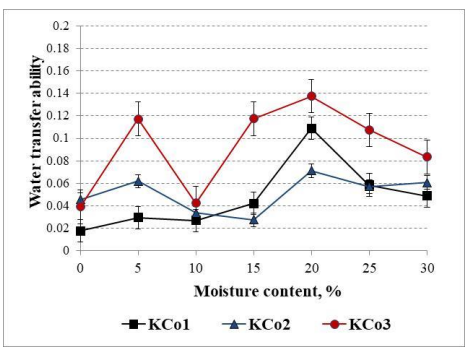
c)

Figure 1: Water transfer ability of KCo1 (a), KCo2 (b), and KCo3 (c) knitted fabrics

An enhanced ability to transfer liquid from the face to the back was also observed in the knitted fabric produced from medium-twisted cotton yarn (KCo2), as shown in Figure 1b. Similar to the KCo1 knit, two zones are distinguished in the graphs that illustrate the liquid transfer ability of KCo2 knit, particularly in the right-to-left direction. In the first zone (up to 10% moisture content), a low moisture content in the knit is associated with a lower ability to transfer liquid. With an increase in moisture content, the size of pores is reduced, leading to accelerated filling of the macropores with liquid and faster moisture wicking to the opposite side of the knit. The effect of the direction of liquid transfer is not clearly expressed for KCo3 knitted fabrics, except at the equilibrium moisture content of the knit, when the liquid transfer ability in the left-to-right direction is higher than that of the opposite direction (Figure 1c). As the moisture content increases (above 10%), the difference in the ability of the left and right sides of KCo3 knit to transfer liquid decreases.



a)



b)

Figure 2: Comparison of water transfer ability of the knitted fabrics in right-to-left (a) and left-to-right (b) direction

Figure 2a compares the liquid transfer ability of the knitted fabrics in the right-to-left direction. The knitted fabrics exhibit similar liquid transfer capabilities in a lower moisture content range. At a moisture content of 15%, the knitted fabrics are characterized by identical liquid transfer abilities. However, in the zone of higher liquid content (above 20%), the trend of increasing liquid transfer ability (with the moisture content increase) is less pronounced in the KCo1 knit. It is common practice for knitted products that the left side (technical back) is in contact with the skin. Therefore, it is particularly important to compare the liquid transfer ability of the knits from left to right. At equilibrium moisture content in cotton knitted fabrics (about 5%), the KCo3 knit exhibits the highest liquid transfer ability, while the lowest liquid transfer ability is observed in the KCo1 knit (Figure 2b). This can be attributed to some differences in stitch density of the knit (Table 1), which resulted from the different twist of the cotton yarns. The lowest stitch density of KCo1 knit indicates the largest dimensions of macropores, explains their slower filling and, consequently, slower liquid transfer through the knit. At a moisture content of 10%, the previously described difference between knitted fabrics in terms of liquid transfer ability disappears. The excess moisture (above the equilibrium content) is absorbed by the fibres, due to which the capillaries in the yarn are closed. Since the highly twisted cotton yarn has the most densely packed fibres, it is possible that the fibre swelling in this yarn led to excessive narrowing of the capillaries (air channels between the fibres in the yarn), which led to a slowdown in capillary action. With higher moisture content (above 10%), some liquid occupies the macropores (pores between the yarns), so adding liquid in the Malden Mills' test will fill the knit's macropores faster, initiating wicking. In this range, KCo3 knit exhibited the highest water transfer ability.

2.2. Water holding capacity

In addition to the absorbed water, liquid can be retained as free liquid in the capillaries or the macropores of the knit. The water holding capacities of the cotton knitted fabrics are presented in Figure 3. Considering KCo1 knit (Figure 3a), the water holding capacity is the same over the whole range of moisture contents (except the equilibrium moisture content when the right side is in contact with liquid), due to the constant number of bonding sites for water molecules. The noted exception requires further investigation. At equilibrium moisture content (4.9%), the water holding capacity of KCo2 knit is the same for both sides (Figure 3b). A similar observation was also noted at higher moisture content (above 25%). In the 5-25% moisture content range, the left side of the knit was characterized by lower water holding capacity. The same trend of water holding was observed in the knit produced from the highest twisted cotton yarn.

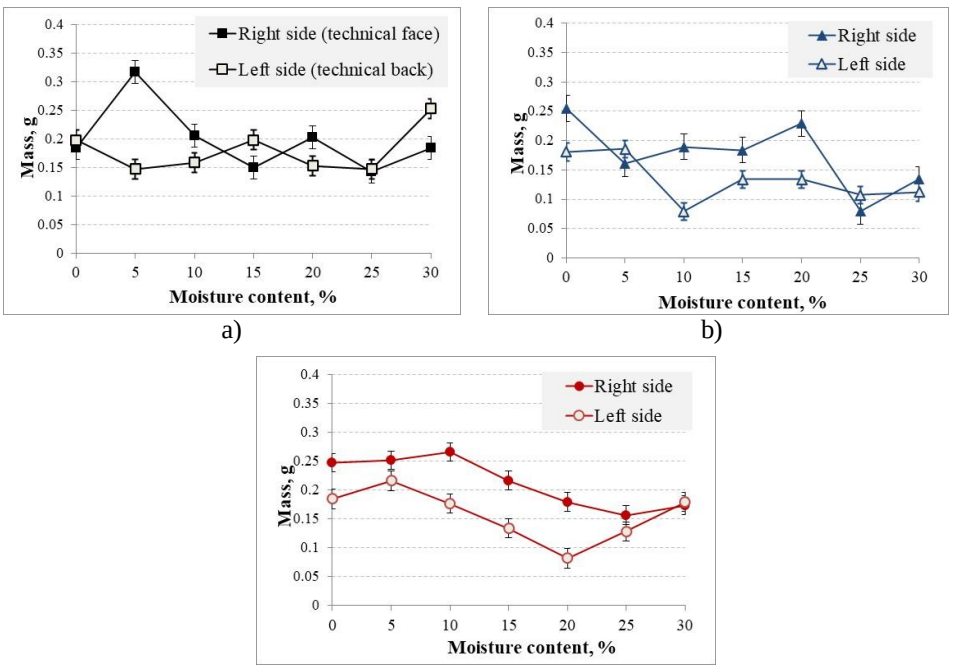


Figure 3: Water holding capacity of KCo1 (a), KCo2 (b), and KCo3 (c) knitted fabrics

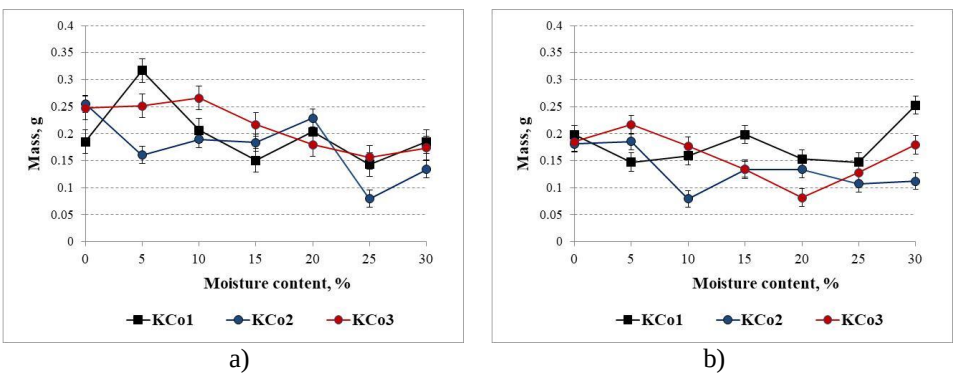


Figure 4: Comparison of water holding capacity of the knitted fabrics in right-to-left (a) and left-to-right (b) direction

The graph in Figure 4a compares the water holding capacity of all three knits when liquid is transferred from the face to the back. At the equilibrium moisture content, the knit from the lowest twisted cotton yarn (KCo1) retains the highest amount of liquid, whereas KCo2 knit (from medium twisted yarn) has the least water holding capacity. Since all three knits have the same density (Table 1), they also have the same bonding sites for water molecules. Therefore, a higher amount of retained water in KCo1 knit can be explained by free water in the knit macropores. As evidenced by the stitch surface density of the cotton knitted fabrics (Table 1), KCo1 knit was characterized by somewhat lower surface density, indicating larger macropore size, which are more easily filled with liquid. With increasing moisture content, the water holding capacity is similar for all knitted fabrics.

When the left side of the knit is in contact with water, the water holding capacity is similar for all tested knits, except for the case of a moisture content of 30%, when KCo1 holds the most water in its structure (Figure 4b). Some of the retained water in KCo1 knit comes from free water held in the capillaries and macropores of the fabric. The KCo1 knits have the largest diameter of capillaries (the channels between fibres) due to the lowest twist of the Co1 yarn. Additionally, because of the reduced loop density, the macropore size in this knit is also the largest. As a result, KCo1 knit exhibits the highest water-holding capacity at a humidity level of 30%.

3. CONCLUSION

The plain cotton knitted fabrics were produced from various twisted yarns under controlled conditions, and therefore, they were characterized by quite similar construction characteristics, such as thickness and areal density, and almost identical bulk density and porosity. However, they differed from each other in the stitch density, which was caused by the different flexibility of various twisted cotton yarns. Such experimental material made it possible to investigate the impact of yarn twist intensity on the liquid transfer properties of textile fabrics. These properties of plain cotton knitted fabrics were determined by two parameters – water transfer ability and water holding capacity. In addition to yarn twist intensity, the experimental variable was the moisture content of the knits.

Considering the water transfer ability, an increase in the ability to transfer liquid is observed when the moisture content in knitted fabrics is above 10%. In addition, the knitted fabrics made from the lowest and medium twisted cotton yarns exhibited enhanced liquid transfer in the face-to-back (right-to-left) direction. The opposite effect is seen with the knit made from the highest-twisted cotton yarn, as it transfers water faster when the left side is in contact.

Only slight variations in the structural and geometric parameters of plain knits resulted in similar behaviour among all tested knits regarding their ability to transfer liquid. However, this trend changes when the moisture content exceeds 20%, as the increase in liquid transfer ability tends to slow down in knits made from the least twisted yarn. In the back-to-face direction, the knit made from the highest-twisted cotton yarn demonstrated improved liquid transfer ability compared to the other two knits tested.

Since the ability to absorb water is primarily determined by the number of functional groups available to form hydrogen bonds with water molecules, the observed similar water holding capacity of the knitted fabrics can be attributed to their comparable structural

characteristics. Differences in the knits' capillary and macropore geometry, resulting from varying yarn twists, were reflected to some extent in their water-holding capacity at higher moisture levels.

As this study examined three different twist levels of yarns to assess how twist level affects the liquid transfer properties of knitted fabrics, the findings cannot be directly applied to knitted fabrics outside the scope of this research. However, what can be generalized is the fact that varying the yarn twists, thereby directly affecting the geometry and distribution of the complex pore system in the knit, can affect the liquid management properties. Further research will involve yarns with a broader range of twist intensity to establish clear guidelines for effective design.

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DETERGENT-INDUCED COLOR CHANGES IN COTTON-BASED FABRICS SUBJECTED TO REPEATED LAUNDERING

Review scientific paper
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ABSTRACT: *Color retention is a fundamental quality metric for textiles, directly influencing consumer satisfaction and environmental sustainability. This study systematically evaluates the effects of 25 laundering cycles on the chromatic stability of light and dark dyed cotton and cotton/polyester blends, utilizing commercially available powder and liquid detergents. Quantitative assessments, including CIELab color coordinates, spectral reflectance-derived color strength (K/S), and color difference (ΔE*), reveal stark contrasts in performance. Powder detergents induce significant dye degradation and color fading, whereas liquid formulations—lacking aggressive bleaching agents—maintain markedly higher color fidelity with substantially lower ΔE* metrics. These findings expose a vital trade-off between chemical aggressiveness and aesthetic preservation, emphasizing the need for environmentally sustainable detergent innovations that optimize fabric care, color longevity, and eco-efficiency. The results inform the development of next-generation textile maintenance protocols balancing performance with sustainability, ultimately supporting eco-conscious consumer choices and industrial practices.*

Keywords: *Color retention, textile laundering, detergent formulation, CIELab color coordinates, color fastness, sustainable fabric care.*

PROMENE BOJE NA TKANINAMA NA BAZI PAMUKA IZAZVANE DETERŽENTOM TOKOM PONAVLJENOG PRANJA

APSTRAKT: *Postojanost boje je fundamentalna metrika kvaliteta za tekstil, direktno utičući na zadovoljstvo potrošača i ekološku održivost. Ova studija sistematski procenjuje efekte 25 ciklusa pranja na hromatsku stabilnost svetlo i tamno obojenih tkanina od pamuka i mešavine pamuka/poliestera, koristeći komercijalno dostupne praškaste i tečne deterdžente. Kvantitativna merenja, uključujući CIELab koordinate boje, jačinu boje izvedenu iz spektralne refleksije (K/S), i razliku u boji (ΔE), otkrivaju oštre kontraste u performansama. Praškasti deterdženti izazivaju značajnu degradaciju boje i gubitak boje, dok tečne formulacije — bez agresivnih agenasa za izbeljivanje — održavaju primetno veću*

vernost boje sa znatno nižim ΔE vrednostima. Ovi nalazi otkrivaju ključni kompromis između hemijske agresivnosti i očuvanja estetike, naglašavajući potrebu za ekološki održivim inovacijama deterdženata koje optimizuju negu tkanina, dugotrajnost boje i eko-efikasnost. Rezultati informišu razvoj protokola za održavanje tekstila sledeće generacije koji balansiraju performanse sa održivošću, na kraju podržavajući ekološki svesne izbore potrošača i industrijske prakse.

Ključne reči: *Postojanost boje, pranje tekstila, formulacija deterženta, CIELab koordinate boje, postojanost boje.*

1. INTRODUCTION

In contemporary textile consumption, garment quality is no longer judged solely by aesthetics or comfort but increasingly by parameters such as durability, ease of care, and environmental impact. Among these, color retention has emerged as a primary determinant of consumer satisfaction, often outranking tactile properties, fabric composition, and price in purchase decisions [1]. The preservation of a fabric's original color appearance throughout its service life is widely recognized as a core indicator of product value and consumer trust. However, color degradation during laundering remains a pervasive challenge within the textile industry, frequently resulting in premature garment disposal, elevated replacement rates, and a greater environmental burden. Garments dyed in solid shades or finished via pigment, reactive, or sublimation printing methods are particularly susceptible to chromatic instability under repeated laundering conditions [2–4]. Ensuring color durability is therefore essential not only for maintaining aesthetic appeal but also for enhancing product longevity and reducing textile waste.

Laundering, the most frequent and chemically aggressive form of garment maintenance, subjects' fabrics to a combination of mechanical, thermal, and chemical stresses that accelerate wear and diminish visual quality. Common consequences include dye fading, bleeding, and loss of whiteness—all of which reduce garment appeal over time [5–9]. These degradative processes not only alter visual perception but have broader implications for textile sustainability, particularly when viewed through the lens of extended product life cycles and circular material flows. According to the Sinner Circle model, laundering effectiveness is governed by the interaction of four critical variables: temperature, time, mechanical agitation, and chemical action [10]. Optimizing one factor often necessitates adjusting others to maintain cleaning efficacy without compromising fabric integrity [11].

Among these, detergent formulation plays a pivotal role in determining both cleaning outcomes and fiber preservation [12]. Commercial detergents are complex chemical systems incorporating surfactants, enzymes, builders, bleaching agents, optical brighteners, and stabilizers [13]. Powder and liquid detergents dominate the global market [14], yet differ significantly in their chemical profiles and interaction with textiles [13,15–17]. Powders commonly contain activated oxygen bleaches and brighteners, which enhance fabric whiteness but may induce oxidative dye degradation, especially in dark-colored

garments [18,19]. In contrast, liquids are typically bleach-free and rely on milder surfactant systems that reduce dye damage while providing adequate cleaning—particularly under lower temperature conditions.

Understanding these formulation-driven effects is critical for advancing sustainable laundering practices, prolonging textile lifespan, and reducing environmental impact [14]. Despite increased commercial availability and eco-labeling, limited research has comparatively evaluated the long-term impact of detergent type on both light and dark color across real-world laundering cycles and fiber blends. This study addresses that gap by assessing optical property changes—CIELab color coordinates and color strength (K/S)—in cotton and cotton/polyester fabrics subjected to 25 domestic wash cycles using commercial powder and liquid detergents. The findings provide robust, data-driven guidance for formulation scientists, textile engineers, and sustainability-focused practitioners.

2. EXPERIMENTAL PART

2.1. Materials

The CIE L*, a*, b* color coordinates, and color strength (K/S) of the control light and dark dyed woven fabrics composed of 100% cotton and cotton/polyester blends are presented in Table 1.

Table 1: CIE L*, a* and b* color coordinates and color strength (K/S) of investigated control unwashed fabrics

Fabric code	Color	Chemical composition	L*	a*	b*	K/S
FL1	light gray	100 % Cotton	85.52	-0.83	0.10	2.2
FL2	light blue	100 % Cotton	60.2	1.77	-13.17	4.9
FL3	light blue	100 % Cotton	78.44	-0.57	-22.67	1.9
FL4	light yellow	100 % Cotton	85.97	2.56	0.98	0.8
FL5	light blue	50% PES/50% Cotton	79.36	0.82	-19.08	1.0
FD1	dark red	100 % Cotton	34.58	41.27	14.99	19.1
FD2	black	35% PES/65% Cotton	18.28	-0.04	-0.64	29.9
FD3	black	45% PES/55% Cotton	17.32	0.13	-1.28	23.2
FD4	black	50% PES/50% Cotton	17.36	0.37	-1.05	22.4
FD5	black	65% PES/35% Cotton	19.98	1.04	-1.34	24.4

2.2. Laundering procedure

Light and dark colored textile fabrics were subjected to rigorous 25-cycle laundering protocols adhering to ISO 6330:2010 standards. Thermal profiles were precisely controlled: 60°C for light fabrics and 40°C for dark. Samples were processed individually using either a complex powder detergent (PD)—featuring surfactants, enzymes, bleaching agents, and optical brighteners—or a distinct liquid detergent (LD)—primarily anionic surfactants with specific fragrance chemistries. Post-wash, all samples underwent vertical air-drying at standardized ambient room temperature to ensure controlled moisture removal kinetics.

2.3. Testing methods

The quality of colored fabrics was evaluated by measuring CIE L*, a*, b* color coordinates, color difference (ΔE*), and color strength (K/S). L*, a*, b* values were obtained using an X-Rite 7i spectrophotometer under D65 illumination with a 10° standard observer, in accordance with ISO 105-J01:1997. Ten readings per sample were averaged. ΔE* was calculated from the CIELab coordinates.

Each fabric sample was categorized based on the magnitude of its ΔE* value into five levels of visual color difference: $\Delta E^* < 0.2$ was considered 'Not visible', $0.2 \leq \Delta E^* < 1.0$ as 'Very small', $1.0 \leq \Delta E^* < 3.0$ as 'Small', $3.0 \leq \Delta E^* < 6.0$ as 'Medium', and $\Delta E^* > 6.0$ as 'Large'. Additionally, ΔE* values were converted into grayscale ratings on a scale from 1 to 5 in accordance with ISO 105-A01:2010. The color strength (K/S), representing the depth or intensity of surface dye, was calculated using the Kubelka–Munk equation based on reflectance values measured at the wavelength of maximum absorption (λ_{max}).The higher the K/S value indicates the higher the color yield of the dyed fabric [2-4].

3. RESULTS AND DISCUSSION

The influence of repeated laundering with powder detergent (PD) and liquid detergent (LD) on fabric color strength is depicted in Figures 2 and 3. Color strength (K/S), a quantitative measure reflecting the intensity and saturation of a fabric’s dye, demonstrated a progressive decline with an increasing number of wash cycles. However, the extent and rate of this decline were significantly dependent on the detergent formulation used. Fabrics subjected to laundering with LD consistently retained a higher proportion of their original color strength across all cycles when compared to those washed with PD, indicating a superior resistance to dye fading.

This difference is primarily attributed to the chemical composition of each detergent type. PD formulations typically contain bleaching agents and optical brighteners intended to maximize the whiteness and luminosity of pale textiles. While effective for light-colored fabrics, these oxidative additives can accelerate dye degradation, weaken dye-fiber bonds, and lead to marked instability in colored textiles, ultimately causing significant loss of color intensity [20]. Conversely, LD formulations are generally devoid of aggressive oxidizers and thus deliver a milder washing action that better preserves the structural integrity of dye molecules and maintains the original color and visual quality of the textiles. These findings

highlight the critical role of detergent chemistry in ensuring optimal colorfastness and in prolonging the aesthetic lifespan of colored fabrics through repeated laundering.

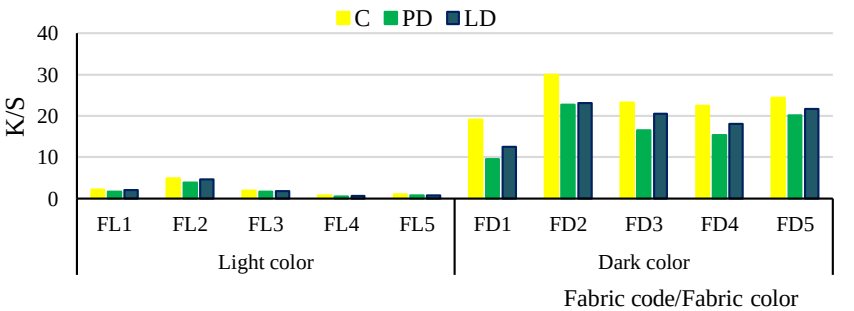

Figure 1: Color strength of light and dark colored fabris before and after 25 washing cycles with powder and liquid detergent

Additional variations in the L*, a*, and b* color coordinates as influenced by detergent type and repeated laundering cycles are presented in Table 2. Fabrics laundered with PD generally exhibited higher L* values, indicating a lighter or brighter visual appearance compared to those washed with LD. Notable changes were also observed in the a* and b* coordinates, which correspond to shifts along the red–green and yellow–blue axes, respectively. These colorimetric shifts were more pronounced in fabrics treated with PD, suggesting that powder detergent has a stronger effect on overall color balance than its liquid counterpart.

Table 2: CIEL*, a* and b* color coordinates, and color strength (K/S) of investigated control and washed fabrics

Fabric code	L*			a*			b*		
	C	PD	LD	C	PD	LD	C	PD	LD
FL1	85.52	89.11	85.46	-0.83	2.36	2.08	0.10	-6.98	-5.72
FL2	60.2	63.61	59.69	1.77	2.77	1.76	-13.17	-13.67	-12.92
FL3	78.44	83.21	79.24	-0.57	-0.48	-0.58	-22.67	-19.45	-19.15
FL4	85.97	86.72	85.65	2.56	2.11	2.29	0.98	-0.95	-0.24
FL5	79.36	81.67	80.98	0.82	1.71	1.64	-19.08	-16.04	-15.89
FD1	34.58	36.15	34.40	41.27	39.59	40.14	14.99	12.08	13.79
FD2	18.28	20.84	18.42	-0.04	-0.46	-0.11	-0.64	-2.58	-1.31
FD3	17.32	19.64	18.71	0.13	-0.84	-0.38	-1.28	-3.06	-2.41
FD4	17.36	20.4	18.53	0.37	0.71	0.69	-1.05	-3.25	-1.59
FD5	19.98	27.35	19.50	1.04	2.08	1.26	-1.34	-3.36	-1.37

Figure 2 compares the color difference (ΔE*) of various fabric codes after laundering, illustrating the effects of PD and LD, with the original (control) fabrics (C). Higher ΔE* values indicate greater color change from the control sample.
Across all fabric codes (FL1–FL5, FD1–FD5), fabrics laundered with powder detergent (C-PD) exhibit consistently higher ΔE* values compared to those laundered with liquid detergent (C-LD). This trend is particularly pronounced in FL1, FL3, and FD5, where ΔE* after PD laundering approaches or exceeds 6–8 units, signifying substantial visible color change. In contrast, the corresponding C-LD values are noticeably lower, especially for FL2, FL4, FD2, and FD5, where the ΔE* remains below 2, indicating superior color retention.
This pattern demonstrates that powder detergent causes greater color alteration, likely due to the presence of bleaching agents and optical brighteners known to accelerate dye degradation. Liquid detergent, in contrast, leads to smaller ΔE* values, thus better preserving the original color of the fabrics.

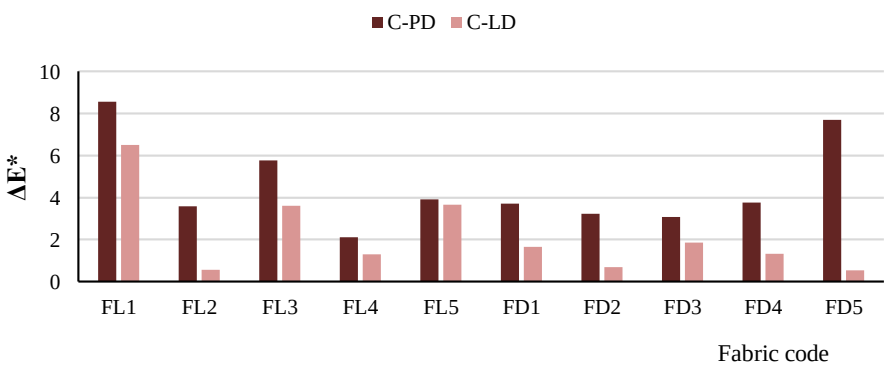

Figure 2: Color difference between the control light and dark colored fabrics (C) and fabric lundered with powder (PD) and liquid (LD) detergents after 25 washing cycles

Fabrics washed with LD mostly showed ΔE* values below 3.0, corresponding to minimal, often imperceptible color changes and high grayscale ratings (4–5). In contrast, PD led to higher ΔE* values (3.0–6.0), signifying more noticeable color changes and reduced colorfastness.

3. CONCLUSION

This study demonstrates that repeated laundering significantly influences the optical properties of both light and dark colored cotton-based fabrics, with outcomes strongly dependent on the type of detergent used. Fabrics washed with powder detergent—containing bleaching agents and optical brighteners—exhibited higher whiteness retention and smaller shifts in L*, a*, and b* color coordinates for textiles. However, the same detergent formulation led to greater lightness and more pronounced color changes (higher ΔE* values) in dark colored fabrics, indicating substantial dye degradation. In contrast,

fabrics laundered with liquid detergent, which lacks aggressive bleaching systems and brighteners, showed superior colorfastness in colored fabrics. These findings underscore the trade-off between enhanced color retention, highlighting the need for tailored detergent selection based on fabric type and desired performance. Moreover, the results contribute valuable insights for the development of detergent formulations and laundering protocols that support both fabric care and sustainable textile maintenance.

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THE FUTURE OF ARTIFICIAL INTELLIGENCE BASED SOFTWARE IN TEXTILE PRINTING

Review scientific paper
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ABSTRACT: *Artificial intelligence (AI) is reshaping the future of textile printing by transforming the way software is used in design, production and quality control. In this paper it will be explored how AI-driven tools are enabling smarter workflows through automated color management, pattern generation, defect detection and predictive maintenance. By integrating machine learning and data-driven decision-making, these solutions offer increased efficiency, reduced waste and greater personalization in textile production. The presented literature overview will also highlight emerging trends, practical applications and the broader implications of AI adoption for both industry and education. It will be highlighted the importance of future AI adoption in textile printing processes. As sustainability and digitalization become central goals, AI-based software is set to play a key role in the next generation of textile printing technology.*

Keywords: *Artificial intelligence, textile printing, software, design.*

BUDUĆNOST SOFTVERA ZASNOVANOG NA VEŠTAČKOJ INTELIGENCIJI U ŠTAMPI TEKSTILA

APSTRAKT: *Veštačka inteligencija (AI) oblikuje budućnost štampe tekstila transformišući način na koji se softver koristi u dizajnu, proizvodnji i kontroli kvaliteta. U ovom radu biće istraženo kako alati zasnovani na AI omogućavaju pametnije tokove rada kroz automatsko upravljanje bojama, generisanje šara, detekciju grešaka i prediktivno održavanje. Integracijom mašinskog učenja i donošenja odluka zasnovanog na podacima, ova rešenja nude povećanu efikasnost, smanjeni otpad i veću personalizaciju u proizvodnji tekstila. Prikazani pregled literature takođe će osvetliti nove trendove, praktične primene i šire implikacije usvajanja veštačke inteligencije za industriju i obrazovanje. Biće naglašena*

važnost budućeg usvajanja AI tehnologija u procesima štampe tekstila. Kako održivost i digitalizacija postaju ključni ciljevi, softver zasnovan na veštačkoj inteligenciji imaće centralnu ulogu u sledećoj generaciji tehnologije štampe tekstila.

Ključne reči: *Veštačka inteligencija, štampa na tekstilu, softveri, dizajn.*

1. INTRODUCTION

The printing process in textile manufacturing can be defined as the localized application of colorants to selected areas of a substrate, typically a textile fabric. In addition to printing, dyeing is also commonly employed in industrial textile processing. The fundamental distinction between these two methods lies in the distribution of color: while dyeing involves the uniform coloration of the entire surface, printing selectively applies colorants to predetermined regions, enabling the creation of complex patterns, multicolor designs, and intricate motifs.

Although printing is nowadays largely associated with paper, the earliest applications of this technique were developed for textile decoration. Historical evidence indicates that textile printing predates paper printing by several centuries. The oldest surviving printed textiles—China's three-color silk prints—are dated to approximately 220 BCE. In contrast, the earliest known dyed cotton samples, discovered in the Indus Valley, are believed to originate from around 3000 BCE [1].

Among contemporary textile printing technologies, screen printing and digital printing are the most prevalent. The comparison between these two techniques remains a subject of ongoing academic and industrial interest, particularly during the current transitional period in which each holds distinct advantages depending on the application context [2].

Screen printing, a conventional technique, involves the creation of stencils (screens), mechanical spreading of ink, and precise alignment during printing. It is widely regarded for its ability to produce vibrant, durable prints with sharp edges and deep color penetration. This method becomes economically favorable for high-volume production runs, as the unit cost decreases significantly with increased quantity.

Digital printing, in contrast, eliminates the need for physical screens and associated setup processes. It relies on computer-controlled printers that apply ink directly onto the substrate, offering greater flexibility, faster turnaround times, and cost-effectiveness for short-run or customized production. However, limitations in color fidelity—particularly in CMYK reproduction—and print durability can still pose challenges when compared to screen printing.

An important development in both screen and digital textile printing is the increasing integration of artificial intelligence (AI). AI-driven technologies are enhancing various stages of the printing workflow, including automated color management, defect detection, pattern generation, and predictive maintenance. The adoption of AI contributes to improved efficiency, reduced waste, and enhanced quality control, marking a significant evolution in textile printing processes [3].

2. THE ROLE OF ARTIFICIAL INTELLIGENCE IN THE PRINTING INDUSTRY

Artificial intelligence (AI) encompasses technologies that enable machines—such as computers or robots—to perform tasks traditionally requiring human cognitive abilities. These include learning, reasoning, perception, language processing, and the ability to draw conclusions from past experiences [4, 5]. In the printing industry, AI-based solutions are increasingly integrated across all stages of production—from prepress and printing to quality control and customer interaction—offering enhanced print quality, cost-effectiveness, and operational efficiency.

Predominantly, AI applications within the graphic arts and printing sectors are rooted in machine learning and computer vision technologies, particularly in the domains of image processing and machine vision [4]. These advancements have facilitated the transformation of traditional workflows, introducing automation, precision, and adaptability across the value chain.

In the domain of design, AI tools assist in automated design generation, image enhancement, and the creation of customized graphics, enabling designers to streamline and elevate creative processes. In prepress operations, AI enables automated proofreading, color correction, file optimization, and trapping, significantly reducing the manual workload and improving throughput.

During the printing phase, AI supports predictive maintenance, quality assurance, ink usage optimization, and workflow automation, all of which contribute to enhanced reliability and cost control. In sales and customer engagement, AI solutions—such as chatbots, virtual assistants, automated quote generation, and follow-up systems—improve response times and client satisfaction [6].

Manufacturers of advanced digital printing systems, particularly those developed for commercial, high-speed, and large-format printing, are increasingly incorporating AI in conjunction with cloud-based and automation technologies. These integrations aim to improve print accuracy, color fidelity, operational efficiency, and profitability [7]. AI-powered features are capable of automatically configuring print settings based on file content, enhancing image resolution, and simplifying preflight checks. Additionally, AI facilitates ink usage prediction and inventory optimization, thus reducing waste and ensuring continuous production.

Job preparation is also automated through AI, and when coupled with cloud connectivity, it enables remote management and on-demand production, thereby minimizing manual interventions. This allows operators with varying skill levels to efficiently handle diverse print tasks [7, 8].

One of the most significant advantages of AI in the printing industry is its capacity to automate repetitive and labor-intensive operations. AI systems can manage tasks such as font recognition, color correction, and image scaling, freeing human resources to focus on more strategic and creative roles.

Furthermore, AI-enhanced software can perform real-time color analysis and adjustments to maintain consistent and optimal output quality. Error detection and correction during the printing process are also facilitated by AI, as the systems can autonomously halt or adjust

production to minimize defects. This automated quality control significantly reduces material waste and lowers production costs.
Moreover, AI contributes to the integration of print media with digital technologies. For instance, printed codes or images can be scanned by users to trigger augmented reality (AR) experiences via smartphones or tablets, enriching user interaction and enhancing the communicative potential of printed materials [6, 8, 9].
In the field of graphic design, AI integration within software tools supports creatives in producing visually optimized, market-relevant content—particularly in areas such as packaging design—by promoting both functional performance and environmental sustainability [8].
Additionally, the incorporation of AI into 3D printing processes is facilitating the creation of more complex and efficient printed models. This not only accelerates the design and production phases but also makes 3D printing technologies more accessible to a wider range of users [8].

3. TEXTILE PRINTING SOFTWARE

In recent years, the textile industry has experienced significant growth in the adoption of digital textile printing technologies. Central to these advancements is the increasing reliance on software solutions that facilitate both the design and production stages. While general-purpose graphic design applications such as Adobe Illustrator and CorelDraw remain widely utilized, textile printing presents unique requirements that necessitate specialized functionalities. Among these are the need for precise pattern repetition, which ensures seamless garment assembly, and meticulous color management to guarantee accurate reproduction across devices and materials [10].
Textile-specific software solutions have emerged to address these demands, integrating features tailored to the intricacies of textile production. Programs such as NedGraphics 2025 offer a comprehensive suite of tools for digital textile printing, including AI-assisted pattern generation, colorway creation, and high-resolution print simulation. The software supports seamless integration with color management systems and digital printing hardware, streamlining workflows for both designers and manufacturers. Additionally, NedGraphics includes plug-ins for Adobe Photoshop and Illustrator, developed by Aquario Design (now operating under the NedGraphics for Adobe brand), enhancing functionalities like pattern repetition and color handling. The latest version introduces improvements such as a tile-based layout for design comparison, a new Colour Reduction Window, and support for the Unified 3D Material (U3M) format, which facilitates realistic 3D simulations of textile behavior [11].

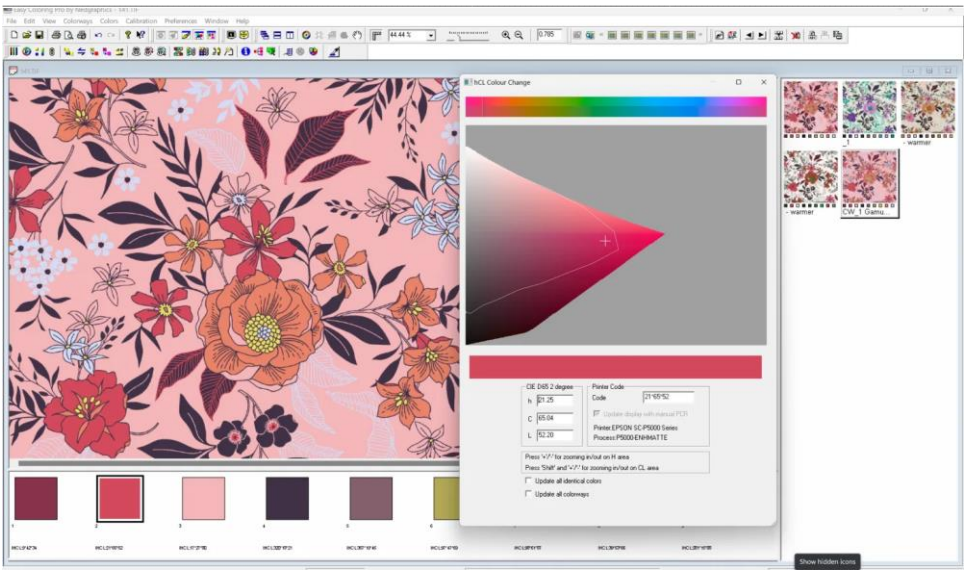

Figure 1: NedGraphics

Optitex serves as a robust 2D and 3D CAD solution designed for apparel and textile production. It enables users to create precise digital patterns and simulate garment behavior in a virtual environment. By supporting the integration of print placement within the virtual prototyping workflow, Optitex reduces the need for physical samples and supports more sustainable production practices [12].

AVA CAD/CAM is another industry-standard software package aimed at textile and surface design professionals. It offers advanced tools for color separations, pattern repeat creation, and print simulation. Known for its sophisticated color management capabilities, AVA supports various output technologies, including inkjet and rotary screen printing. The most recent version, AVA v5.9, features a redesigned user interface, automation tools, enhanced text functionality, and expanded color file compatibility, including support for Adobe Swatch Exchange and ICC 4.3 profiles. Its integration with PrintFactory ensures compatibility with a broad range of textile printers [13].

Figure 2: Optitex

Figure 3: AVA

The Pointcarre software suite, developed by the French-American company of the same name, encompasses modules for digital printing, weaving, and knitting. It includes a color engine capable of simulating both rotary and digital printing outputs, ensuring accurate color sampling and consistency.

The latest innovation, 'Design Maker,' introduces a generative AI tool developed specifically for textile design. Unlike generic image-generation tools, Design Maker is optimized for creating repetitive patterns and integrates with Pointcarre's Jacquard Maker and ColorSep modules.

With support for multiple formats and customization options, this AI-powered functionality enhances the creative workflow while ensuring technical precision. Pointcarre remains committed to simplifying textile design processes, enabling designers to focus on creativity and color development [14].

Figure 4: Pointcarre

InEdit is a specialized software platform for digital textile printing, particularly known for its strong capabilities in print job and color data management. Designed for compatibility with industrial and large-format printers, InEdit includes features such as ICC profiling, step-and-repeat patterning, and support for variable data printing. It is most recognized for the NeoStampa RIP, a widely adopted solution for digital printing. Additionally, InEdit provides design tools such as NeoTextil, a plug-in for Adobe Photoshop that includes modules for pattern repetition (nT Step and Repeat), automated color separation (nT Masquerade), color variant creation (nT Colorations), and photorealistic simulation (nT Virtual Vision) [15].

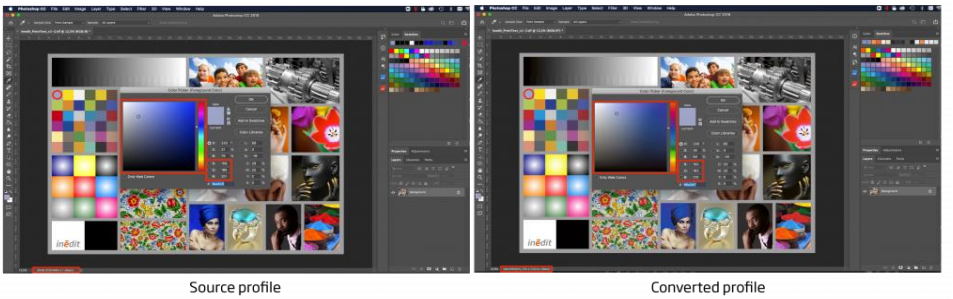

Figure 5: InEdit

The digital textile printing market is supported by a diverse range of mature software solutions, each offering unique strengths. The choice of software often depends on specific workflow needs, design preferences, and compatibility with supply chain partners. As textile printing continues to evolve, particularly with the integration of artificial intelligence and 3D visualization technologies, these platforms will play an increasingly critical role in enhancing efficiency, creativity, and production sustainability.

4. CONCLUSION

The integration of artificial intelligence into textile printing software marks a transformative shift in the design and production processes of the textile industry. AI-driven solutions are increasingly influencing key aspects of digital textile workflows, including automated color management, pattern generation, defect detection, and predictive maintenance. These technologies offer not only improvements in operational efficiency and production speed but also significant advancements in customization, accuracy, and sustainability.

Specialized software packages such as NedGraphics, Optitex, AVA CAD/CAM, Pointcarre, and InEdit demonstrate how AI capabilities are being effectively embedded into commercial design and manufacturing environments. These platforms support intelligent automation, enhance visualization through 3D simulation, and promote environmentally conscious practices by reducing material waste and minimizing the need for physical sampling.

As textile manufacturing continues to shift toward digitalization and sustainable production models, the role of AI-based software is expected to expand further. Future developments will likely focus on deeper integration with smart manufacturing systems, real-time data analytics, and generative design tools that support creative exploration while ensuring production feasibility.

Ultimately, the adoption of AI in textile printing represents more than a technological upgrade—it signals a paradigm shift in how textiles are conceived, produced, and consumed. Embracing these innovations will be essential for companies aiming to remain competitive in an increasingly digital and sustainable global market.

ACKNOWLEDGEMENT

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DYEING COTTON WITH BIFUNCTIONAL REACTIVE DYE IN SEA WATER

Professional paper
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ABSTRACT: *Traditional dyeing of textiles requires the use of a large amount of fresh water, which in combination with the use of large amounts of salt and auxiliaries contributes to significant environmental pollution. Using sea water as a textile dyeing medium is an innovative and environmentally friendly approach that addresses the challenges associated with conventional fresh water dyeing methods. The primary advantage of using sea water for textile dyeing is its high availability and high NaCl content. In this work the possibility of dyeing cotton with reactive bifunctional dye Bezaktiv red S-3B$_{150\%}$ in sea water was examined based on a comparative analysis with the results of dyeing in distilled water. Simulated and real sea water were used in the work. Dyeing was performed with 1% and 3% dye. Dyeing in a sea water bath was performed without the addition of NaCl or with a 38% (dark tone) and 50% (light tone) reduced amount of NaCl added to a distilled water bath. The results obtained by reflection spectrophotometry indicate that it is possible to dye cotton fabric with the selected reactive dye in a light shade in sea water because the color intensity (K/S) is approximately the same as the color intensity achieved with distilled water. And dyeing in a dark shade shows practical potential because the intensity of the color was lower by 30%, and it is possible to achieve better results by further improving the process (e.g. filtering water).*

Key words: *cotton, sea water, reactive dye, color intensity.*

BOJENJE PAMUKA BIFUNKCIONALNOM REAKTIVNOM BOJOM U MORSKOJ VODI

APSTRAKT: *Tradicionalno bojenje tekstila zahteva upotrebu velike količine slatke vode, koja u kombinaciji sa upotrebom velikih količina soli i pomoćnih sredstava doprinosi značajnom zagađenju životne sredine. Korišćenje morske vode kao medijuma za bojenje tekstila predstavlja inovativan i ekološki prihvatljiv pristup koji se bavi izazovima povezanih sa konvencionalnim slatkovodnim metodama bojama. Primarna prednost upotrebe morske vode za bojenje tekstila je njena velika dostupnost i sadržaj velikih*

količina NaCl. U ovom *radu ispitana je mogućnost bojenja pamuka reaktivnom bifunkcionalnom bojom Bezaktiv red S-3B$_{150\%}$ u morskoj vodi na osnovu komparativne analize sa rezultatima bojenja u destilovanoj vodi. U radu je korišćena simulirana i prava morska voda. Bojenje je izvedeno sa 1% i 3% boje. Bojenje u kupatilu sa morskom vodom izvedeno je bez dodatka NaCl ili sa 38% (tamni ton) i 50% (svetli ton) smanjenom količinom NaCl koja se dodaje u kupatilu sa destilovanom vodom.*
Rezultati dobijeni refleksionom spektrofotometrijom ukazuju da je moguće bojiti pamučnu tkaninu izabranom reaktivnom bojom u svetloj nijansi u morskoj vodi jer je intenzitet boje (K/S) približno isti kao intezitet boje postignut destilovanom vodom. I bojenje u tamnoj nijansi pokazuje praktični potencijal jer je intezitet boje bio manji za 30%, i moguće je daljim poboljšanjem procesa (npr. filtriranjem vode) postići bolje rezultate.

Ključne reči: *pamuk, morska voda, reaktivna boja, intenzitet obojenja.*

1. INTRODUCTION

Clothing color plays a key role in the fashion industry, as it is the first feature consumers notice about a garment. Textile dyeing is an important stage of the technological process of textile production that consumes large amounts of water, chemicals and energy. In the textile industry, the current dyeing practice is problematic due to intensive water consumption and pollution. Cotton dyeing is particularly water intensive, as about 125 liters of water can be consumed per kilogram of cotton fibers for dyeing and finishing [1]. This water is returned to nature as toxic waste, which contains residual dyes and dangerous chemicals. One billion USD worth of dyeing is lost annually to waste water due to inefficient dyeing and finishing processes [2]. Were identified 72 toxic substances in the waste water from the textile dyehouse, 30 of which cannot be removed. Salts make up close to 50% of pollution and contribute the most to high values for total dissolved solids (TDS), bichemical oxygen consumption (BOD) and chemical oxygen consumption (COD) [3]. Water covers about 71 % of our planet's surface, but only 3,5% of all water on Earth is fresh water and most of it is frozen in the polar ice caps. Ground water accounts for 31% of the total fresh water, which is not easily accessible. The most accessible form of fresh water is found in lakes, rivers and reservoirs and it comprises only 0,3% of the total fresh water resource [4]. More recently, sea water has been studied as a possible processing medium for cotton dyeing, as it contains large amounts of inorganic salts. Ferreira et al. recently used sea water as an alternative for dyeing with reactive dyes [5]. They used colors of different functional groups and concentrations of 0,1% to 5% by weight of the material. In the sea water bath, NaCl was added only in the three highest concentrations. Samples dyed in a light shade (0,1%) had a higher intensity when dyed in sea water. In other concentrations, a higher intensity of coloring was achieved in distilled water, which led the authors to the conclusion that it is necessary to improve the process of using sea water for better results. Recently, sea water has been used for dyeing cotton and polyester fabrics [6]. The use of sea water in the dyeing of these fabrics contributed to a greater intensity of color on cotton by 15% and polyester by 3%. The aim of this work is to study the possibility of using sea water as a processing medium for dyeing cotton with a bifunctional reactive dye.

The assessment of the usability of sea water as a suitable medium for dyeing was carried out on the basis of the comparative quality of cotton dyeing in distilled water, simulated sea water and real sea water.

2. EXPERIMENTAL PART

2.1. Material and working methods

In the experiment, fabric samples of 100% cotton, surface weight 220 g/m^2, were dyed. The fabric is industrially prepared for dyeing. The samples for dyeing had a mass of 3 g. The volume of the bath was 160 cm^3. The following chemicals were used in the work:
Bezaktiv red S-3B$_{150\%}$, bifunctional reactive dye (VS/MCT, Bezema, Switzerland), NaCl – salt, agent for increasing dye exhaustion, Na_2CO_3 – salt, agent for regulating the pH of the solution. Dyeing was performed using in Ahiba apparatus (TYPE G7B) in glass cuvettes with vertical movement of the material. The dye concentration was 1 and 3% by weight of the material, NaCl concentration 0-80 g/dm^3 and Na_2CO_3 concentration 10 and 20 g/dm^3. The dyeing solution formulations and sample designations are shown in table 1. The pH of the bath was 10,5 - 11. Dyeing was performed in distilled, simulated sea water and real sea water. Table 1 contains sample designations depending on the dyeing bath formulations. Dyeing was performed using the all-in method, according to the dyeing profile shown in figure 1.

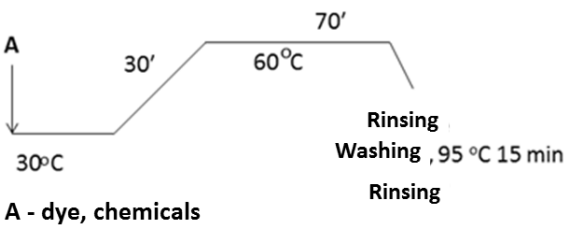


Figure 1: Dyeing profile of dye Bezaktiv red S-3B$_{150\%}$

Table 1: Sample designations and dye bath composition

Designations of samples	Water	Conc. dye, %	NaCl, g/dm^3	Na_2CO_3, g/dm^3
P1	**DW**	**1**	**50**	**10**
P2	SMW	1	25	10
P3	**DW**	**3**	**80**	**20**
P4	SMW	3	50	20
P5	PMW	1	0	10
P6	PMW	1	25	10
P7	PMW	3	0	20
P8	PMW	3	50	20

DW- distilled water; SMW – simulated sea water; PMW – real sea water (Aegean Sea)

The composition of the simulated sea water is presented in [7]. The reflectance of the samples at wavelengths of 400–700 nm was measured using a Spectraflash SF600X reflection spectrophotometer (Datacolor – USA) and the CIELab color coordinates were determined.

Based on the reflection value at the wavelength of maximum adsorption for each sample, the color intensity (K/S) was calculated according to the Kubelka-Munk equation: $\frac{K}{S} = \frac{(1-R)^2}{2R}$ The wavelength of maximum adsorption for Bezaktiv red S-3B150% is 550 nm.

Based on the color intensity before and after soaping, the degree of dye fixation, F(%), was determined using the following equation:

$$F = \frac{\left(\frac{K}{S}\right)_T}{\left(\frac{K}{S}\right)_0} \cdot 100$$

where the subscript *T* refers to the fabric treated in a soap solution, and the subscript *0* to the untreated fabric, immediately after dyeing.

3. RESULTS AND DISCUSSION

Figure 1 shows the reflectance diagrams of cotton fabrics for different dye concentrations. The area below the reflection curve shows the reflected energy, and the area above the reflection curve shows the absorption energy. Samples dyed with 1% Bezaktiv red S-3B$_{150\%}$ (image a) have higher reflection energy, compared to samples dyed with 3% dye (image b). In the entire interval of wave lengths, the samples dyed with the standard recipe in distilled water have the lowest reflection energy. This color has minimum absorption in the sector of complementary green colors, i.e. at 550 nm.

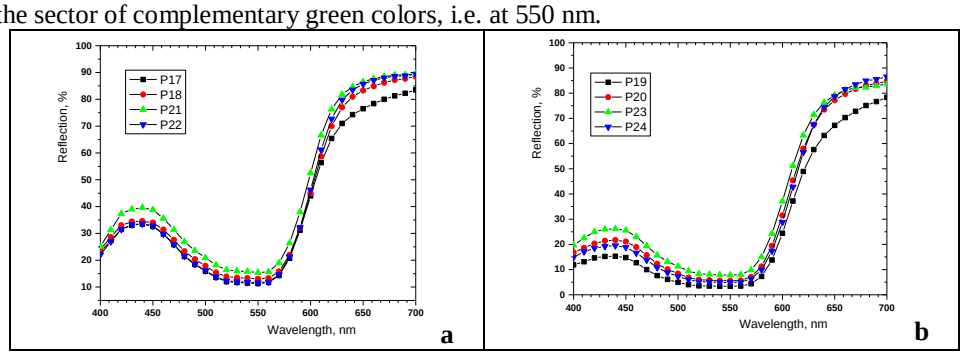


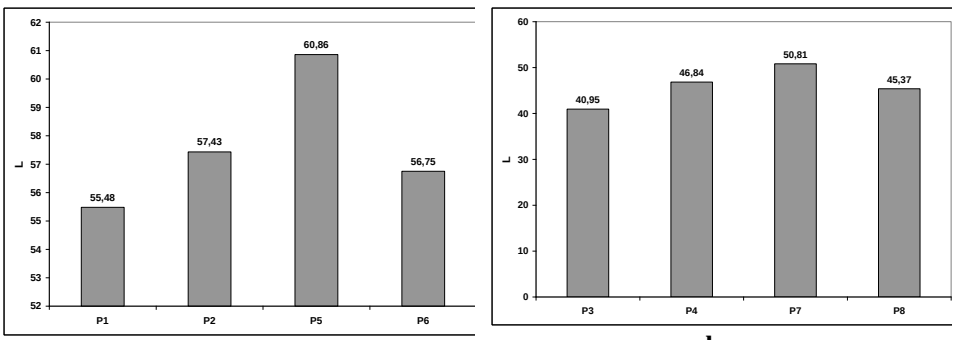
Figure 1: Reflectance of cotton fabric samples dyed with Bezaktiv red S-3B$_{150\%}$ 1% (a); and 3% (b)

L* is the vertical coordinate of the three-dimensional CIELab system and shows the similarity of chromatic colors with achromatic colors. The higher the value of L*, the more similar a chromatic color is to white – an achromatic color. Compared to the sample dyed

in distilled water with a standard recipe - sample P1 (c=1%), the samples dyed in sea water - samples P2, P5 and P6, have higher values of the L^* coordinate (figure 2).

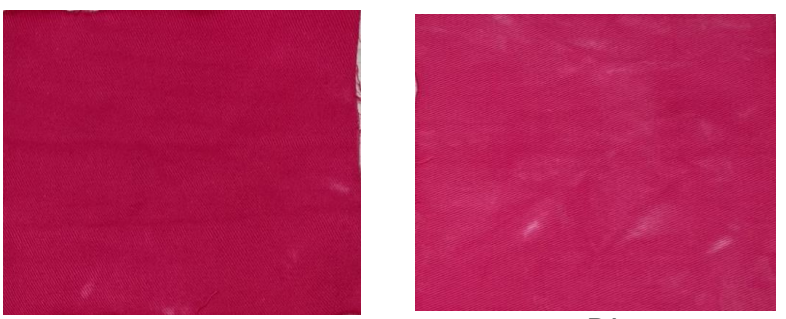
On samples dyed in sea water, the values of the lightness coordinate L^* are 10-15% higher than on the sample dyed in distilled water, for the dyeing system with 3% Bezaktiv red S-$3B_{150\%}$. Sample P7 dyed in real sea water without the addition of NaCl has the highest lightness value. And visually in figure 3 it can be seen that sample P7 has the tone of the lowest intensity.

All samples dyed in simulated or real sea water have lower intensity compared to samples dyed in distilled water. In the process of dyeing cotton with reactive dyes, the presence of NaCl is necessary in order to transfer the color from the solution to the fiber. The presence of NaCl in the bath manifests itself as an increased exaustion of dye from the technological solution, i.e. as a higher color intensity on fabric samples.

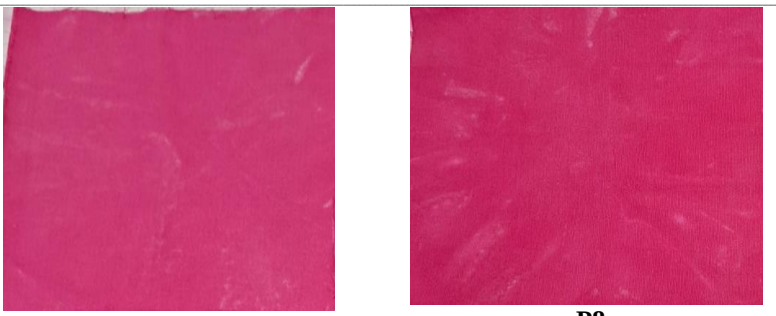


a **b**

Figure 2: Color lightness L^* of samples dyed with Bezaktiv red S-$3B_{150\%}$ 1% (a); and 3% (b)



P3 **P4**

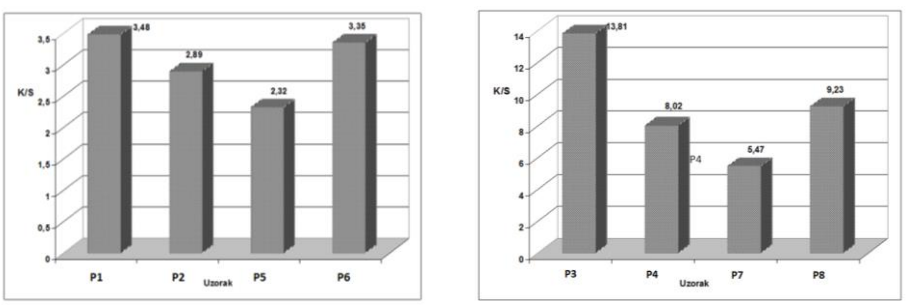


P7 **P8**

Figure 3: Photographs of samples dyed with 3% Bezaktiv red S-3B$_{150\%}$

Samples dyed in simulated sea water had about 15% (for a lighter tone, Fig. 4a) and about 40% less intensity (for a darker tone, Fig. 4b) of color, due to a reduced concentration of NaCl by 50% and 38%, respectively, compared to the standard recipes. Samples P5 and P7 that were dyed in a bath with real sea water and without the addition of NaCl (only Na_2CO_3 added) have by far the largest drop in color intensity, namely 33% (for a lighter tone) and 60% (for a darker tone). For the practice of dyeing, the approach of dyeing in real sea water with a reduced concentration of NaCl makes sense. It is possible to dye a light tone in real seawater with 50% less NaCl (compared to the standard recipe) because the color intensity on the cotton fabric is only 4% lower, compared to the sample dyed in distilled water. When dyeing in a shade with 3% color, the color intensity of the sample is lower by 33% (conc. NaCl lower by 38%, sample P8).

The degree of fixation F, the values of which are shown in Table 2, shows what proportion of the total dye consumed is fixed to cotton cellulose by establishing a covalent bond. From the results shown, it can be assumed that the change in the process medium in the studied dyeing system had no effect on the covalent fixation of the dye, i.e. the reaction of reactive groups with the ionized hydroxyl group of cellulose. The values for the degree of fixation of reactive dye F had approximate values.



a **b**

Figure 4: Color intensity samples dyed with Bezaktiv red S-3B$_{150\%}$ 1% (a); and 3% (b)

Table 2: Degree of fixation (F) of dye Bezaktiv red S-3B$_{150}$% on samples of cotton fabric

Designations of samples	F, %
P1	**85**
P2	84
P3	**81**
P4	86
P5	86
P6	83
P7	80
P8	82

4. CONCLUSION

By dyeing textiles in sea water, it is possible to reduce the amount of sodium chloride added to the dyeing bath, because sea water is a natural resource that contains salt. The results obtained by reflection spectrophotometry indicate that it is possible to dye cotton fabric with the selected bifunctional reactive dye Bezaktiv red S-3B150% in light shades with a salt amount that is 50% lower than in standard dyeing, since under this condition approximately the same dyeing intensity was achieved. Dyeing in darker shades also shows practical potential because when the salt concentration (NaCl) is reduced to 38%, the color intensity is reduced by 1/3 of the standard intensity. Further process improvement is needed for better results. This involves preparing the water to reduce its hardness and possibly removing some chemicals – e.g. by filtration – that affect the interaction of dyes with fibers.

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DEVELOPMENT AND CHARACTERIZATION OF HERBAL-FINISHED BANANA/COTTON BLENDED FABRIC FOR SUSTAINABLE YOGA MATS

Original scientific paper
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ABSTRACT: *The ultimate aim of the paper is to develop a yoga mat using different blends of banana with cotton. By using these blended yarns the woven fabric is produced and the produced fabric is taken for pre-treatment process by using soapnut and charcoal to remove the natural impurities present in the fibre and then the fabric is dyed with eco–friendly natural dyes also the eco-friendly natural dyed fabric is printed with Azadirachta indica and Ocimum tenuiflorum. Treated fabric is tested for the comfort and aromatic properties and then taken for manufacturing. The manufactured product contributes to comfort, hygenic, thermal and ecological factor.*

Keywords: *Banana/Cotton Blended fabric, eco-friendly natural dyed fabric, Azadirachta indica, soapnut, Ocimum tenuiflorum, Yogamat Fabric.*

RAZVOJ I KARAKTERIZACIJA TKANINE OD BANANE I PAMUKA OBRAĐENE BILJNIM MATERIJALOM ZA ODRŽIVE PROSTIRKE ZA JOGU

APSTRAKT: Krajnji cilj rada je razvoj prostirke za jogu koristeći različite mešavine banane i pamuka. Korišćenjem ovih mešanih pređa proizvodi se tkana tkanina, koja se podvrgava procesu prethodne obrade pomoću sapunskog oraha i uglja kako bi se uklonile prirodne nečistoće prisutne u vlaknima. Zatim se tkanina boji ekološki prihvatljivim prirodnim bojama. Takođe, ekološki prihvatljiva prirodno obojena tkanina se štampa sa Azadirachta indica i Ocimum tenuiflorum. Obrađena tkanina se testira na udobnost i aromatična svojstva, a zatim se koristi za proizvodnju. Proizvedeni proizvod doprinosi udobnosti, higijeni, termičkom i ekološkom faktoru.

Ključne reči: Tkanina od mešavine banane/pamuka, ekološki prihvatljiva prirodno obojena tkanina, Azadirachta indica, sapunski orah, Ocimum tenuiflorum, Tkanina za prostirku za jogu.

1. INTRODUCTION

Clothing and apparel products made of synthetic fibres like polyester and nylon adds to microplastic pollution, which can end up in the ocean and pose a hazard to marine life. Each year, 1.5 million tonnes of microplastics wind up in the ocean, with synthetic fabrics accounting for 35% of the total. Apparel is the most basic requirement for human survival in this environment. However, we are in a predicament where we must save our planet, 'THE EARTH.' Synthetic fibres, on the other hand, pollute the environment in a variety of ways, including contaminating the air, affecting the ecology, and so on. In this situation, the entire world is moving away from environmentally friendly and sustainable fashion. Customers are becoming more environmentally mindful as well. As a result, there is a high demand for sustainable items on the market.

2. LITERATURE REVIEW

2.1. Selection of material

Natural fibres are increasingly used in composites due to their inexpensive cost and outstanding mechanical qualities. These are promising prospects for the development of agro-based fibres. Banana fibres have a great potential as a natural fibre among the existing agro-based, natural cellulosic fibres. Its long-term viability is clear, and it offers untapped potential in the textile industry. There are several options in India for extracting fibres from banana stems [1].

2.2. Banana production and availability

Musa acuminata (banana) is a Musa species. Banana cultivation is a prominent agricultural activity in India since it is a valuable fruit crop. The wide area of cultivation that can offer a substantial amount of fibres produces a large amount of trash [2]. Various portions of the banana plant, such as banana skins, leaves, and stems, produce around that are not directly used. Banana pseudo-stems can produce fibres of various sizes. The pseudostem may produce 600 kg of fibre per hectare, which has been proven to be helpful for a variety of purposes [3].

2.3. Extraction of banana fibre

A machine that eliminates bark, skin, wood, stalks, grain from trees, hard to peel, is shown in Figure 1.

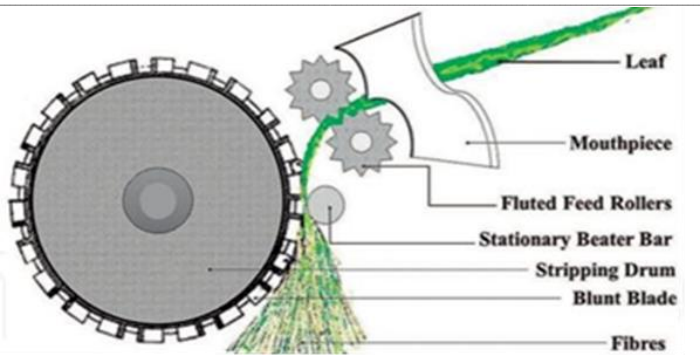


Figure 1: Machine for Pseudo stem extraction [5]

2.4. Characteristics of banana fiber

Banana fibre has a similar appearance to bamboo and ramie fibre, but its fineness and spinnability are superior to the two. It can be spun in a circle using practically any method, including ring spinning, open-end spinning, bast fibre spinning, and semi-worsted spinning, among others [3].

2.5. Application of banana fiber

Banana plants are the best source of fibre, as well as having several additional purposes such as therapeutic, alcohol, starch extraction, and many more[4]. This banana fibre is used to make high-quality textiles in Japan and Nepal [5]. Banana fibres are mostly used to make marine cordages, cardboards, tea bags, string thread, fabric material, and tying rope. In Japan, banana fibres are utilised to make traditional ceremonial robes [5]. In Nepal, the plant's outer sheath is used to make place mats, floor mats, and sun screens.

2.6. Banana fiber structure and properties

Banana fibres contain robust walls that are held together by hemicellulose, pectin, and lignin [6]. The "pith" is the section of a sheath that isn't made of fibre. Taking the pith out of the banana sheaths, on the other hand, has no effect on the content of the fibre strands, but it does liberate fibres from the sheath [7].

Table 1: Fiber components of Banana [8]

Fiber	Banana
Cellulose(%)	60-85
Hemicellulose (%)	6-8
Lignin (%)	5-10
Pectin (%)	2.5-4
Ash (%)	7-21

When degummed, the cell wall thickness of banana fibre measured 8.3 m, which was not substantially different from that of sisal (approximately 12.8 m) and ramie (about 11.5 m) according to some research [9,10]. The use of banana fibre in the textile industry is limited

by its hydrophilicity, coarse fineness, poor elasticity, lack of cohesiveness, increased yarn unevenness, and hairiness [11]. Pretreatment and material preparation, on the other hand, can improve fineness and mechanical properties [12,13].

2.7. Cotton fiber production and availability

Various species of cotton grown as crops are native to most of the world's subtropical regions and have been domesticated many times independently. Within 80-100 days after planting, the plant blooms white flowers, which turn reddish. The fertilized flower falls after a few days and replaces it with a small green triangular pod called a ball. This pod matures in 55-80 days [14].

2.8. Extraction of cotton fiber

The cotton bundle is opened, and its filaments are raked precisely to eliminate unfamiliar matter (e.g., soil and seeds). A picker (picking machine) then, at that point, wraps the strands into a lap. A card (checking) machine brushes the free strands into lines that are joined as a delicate sheet, or web, and structures them into free untwisted rope known as card bit [15].

The methodology for meshing cotton yarn into texture is like that for different filaments. Cotton looms join the strained the long way yarns, called twist, with transversely yarns called weft, or filling. Twist yarns regularly are dealt with artificially to forestall breaking during weaving [16].

2.9.Degumming of banana fibre

Banana fibers obtained after the different degumming treatments was evaluated for the physical, chemical and mechanical properties so as to ascertain the effect of enzyme activity on the quality of treated fibers (Figure 2).

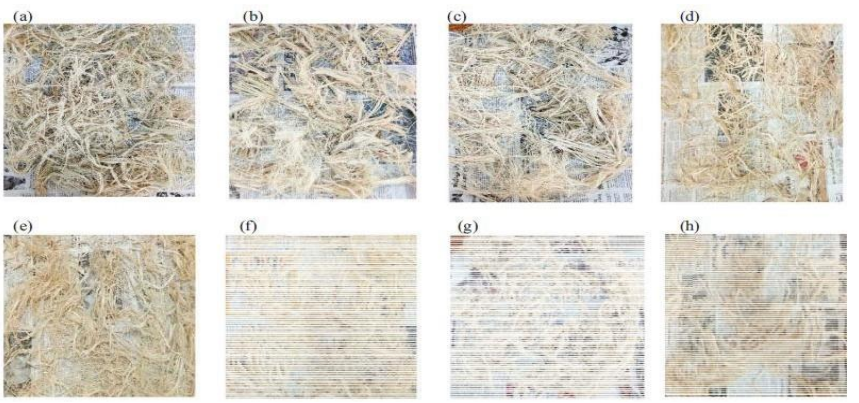


Figure 2: Segregation of fiber after degumming process (a), (b), (c) and (d) (T1-T4) are different enzymatic treatments in Red Banana variety and (e), (f), (g) and (h) (T1-T4) are treatments followed in Popoulu variety.

2.10. Spinnability of banana fibre

Once fibers were treated by enzymatic means and characterized, fibers were introduced into a lab-scale spinning plant. A Shirley opener for short fibre was used before introducing the fibers into the carding flats. The absolute humidity during fiber processing was 17 g/kg dried air, as previous experiences have shown that stiff fibers have better processability when working at high humidity rates. Due to the difficulty of banana fibers spinning, they were mixed with cotton, polyester and wool. Once the wick was produced, the following step was carried out in an industrial twist roving Electro-Jet .The spinning process took place in a continuous ring spinning machine. The yarn was then twisted in a ring twister, the filaments were twisted at 400 laps/m, in an S sense; and the spindles ratio was 2000 laps/min with a production of 5 m/min [17].

2.11. Weaving of banana and cotton blended of yarn

That plain 1/1 has recorded the high rates of fabric weight followed by twill 2/2 & satin 4 respectively. This is due to decreases the float length in weave structure lead to an increase in the number of intersections per unit area in the produced fabrics and increase the yarns crimp, as a result the fabric areal density increased [18].

2.12. Natural dyeing of banana and cotton blended fabric

Banana fibers, extracted from the sheath, can be utilized for manufacturing fiber, can diminish the pressure on the jute fiber. A Jute-Banana hybrid fabric (JBHF) was developed by using Jute yarn (12 Ne, in warp) and Banana yarn (18 Ne, in weft). In order to evaluate physico- mechanical properties of naturally dyed Jute-Banana hybrid fabric, different tests like Stiffness, Thickness, Tensile strength, Tear strength, Drape and Crease recovery were conducted which provided satisfactory results. Colorfastness to wash, water, rubbing and perspiration of naturally dyed Jute- Banana hybrid fabrics (JBHF) also provided acceptable outcomes. FTIR test also provided the confirmation of this two fibers and Spectrophotometer was used to illustrate the dyeing quality. It was an endeavor to minimize the dependency on a single quality fiber and find an alternative way to prepare the hybrid fabric by blending two different quality natural fibers. [19]

2.13. Madder

The creation and application of natural dyes, such as madder, has received increasing attention from various researchers as environmental protection awareness has grown. They are obtained from natural resources and renewable, and therefore, their uses will continue to inspire scientists due to their ecological, antimicrobial, and UV protection characteristics [20,21]

3. MATERIALS AND METHODS

3.1 Materials

In this study, Banana and Cotton fiber were used to made a sustainable yoga mat which is dyed with natural dyes madder and printed with neem and tulsi leaves.

3.1.1. *Banana fiber*

Banana Fiber is sourced from NRCB, Trichy, Tamil Nadu, India as shown in Figure 3. It consists of cellulose, hemicellulose, and lignin.

Figure 3: Banana Fiber

3.1.2. *Banana fiber specification*

Banana fibres contain robust walls that are held together by hemicellulose, pectin, and lignin [6,22]. The "pith" is the section of a sheath that isn't made of fibre. Taking the pith out of the banana sheaths, on the other hand, has no effect on the content of the fibre strands, but it does liberate fibres from the sheath. Mechanical properties and specification of Banana Fiber are shown in Table 2.

Table 2: Mechanical properties and specification of Banana Fiber

Fiber	**Banana**
Fiber Diameter (µm)	8.3
Moisture content (%)	9.8-12
Density (g/cc)	1.350
Microfibrillar angle (◦)	11-15
Tensile strength (Mpa)	550±6.8
Fiber Denier(g/denier)	29.98
Fiber Length(mm)	10
Dry (g/tex)	34.86
Elongation %	2.40
Handle	Very coarse
Hydroscopic Nature	Absorbent
Young’s modulus	3.5

3.1.3. *Cotton fiber*

Raw cotton fiber is sourced for Best Cotton Mill, Tirupur, Tamil Nadu, India. It is a natural cellulose fiber that has the natural Microbial activity.

3.1.4. *Cotton fiber specification*

Specification and properties of cotton is shown in Table 3.

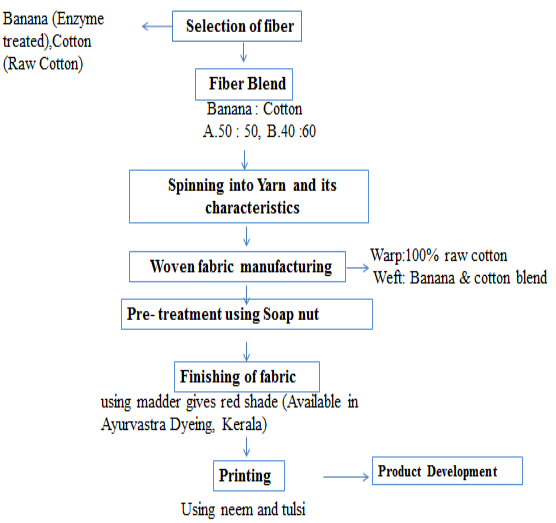
Table 3: Specification and properties of cotton

Fiber	Cotton
Fiber Diameter (µm)	10
Moisture content (%)	7.1
Density (g/cc)	1.5
Microfibrillar angle (◦)	10-12
Tensile strength (Mpa)	264-654
Fiber Denier(D)	2.0 D
Fiber Length(mm)	1.30mm
Dry (g/tex)	27-44
Elongation(%)	9.5%
Handle	Softer
Hydroscopic Nature	Super Absorbent
Young's modulus	5 to 12

3.2.Methodology

In the below flow chart explains the process of the Banana and cotton blended fabric to make home textile product.

3.2.1. *Flow chart*



4. TESTING

Testing ensures the safety, quality and performance of their goods. Tests can be carried out on items ranging from fibre samples to finished products.

5. RESULTS AND DISCUSSION

5.1. Yarn test

5.1.1. *Yarn count*

The yarn count of the yarn samples has been given in the above table. The result shows that both the blends have same count.

5.1.2. *Yarn twist per inch and twist direction*

The result shows that both the blends have 36 TPI and in S direction.

5.1.3. *Tensile strength*

The tensile strength of a B40:C60 shows good tensile strength than the B50:C50.Since the cotton fibre captured the high areal density than the banana because of its length and weight.

5.1.4 *Elongation*

As similar to the tensile strength, the B40:C60 shows good elongation than B50:C50 blend and the B50:C50 shows lower elongation than B40:C60.

5.2. Fabric testing

5.2.1. *GSM*

The B40:C60 blend shows high GSM than the other blend, Since the cotton can hold high areal density than banana.

5.2.2. *Thickness*

The thickness of the weaved fabric has been given in the table. As similar to the GSM, the B40:C60 shows higher thickness than B50:C50 blend and the B50:C50 shows lower thickness than B40:C60.

5.2.3. *Stiffness*

The B40:C60 shows higher stiffness than B50:C50 blend and the B50:C50 shows lower stiffness than B40:C60.

5.2.4. *Water vapour permeability*

The B50:C50 shows higher Water Vapour than B40:C60 blend and the B40:C60 shows lower Water Vapour than B50:C50.

5.2.5. *Tearing strength*

The B50:C50 shows higher Tearing Strength than B40:C60 blend in both warp and weft direction and the B40:C60 shows lower Tearing Strength than B50:C50 in both warp and weft direction. But, the variation is in very low deviation.

5.2.6. Air permeability

The B50:C50 shows higher Air Permeability than B40:C60 blend and the B40:C60 shows lower Air Permeability than B50:C50.

5.3 Natural dyed fabric testing

5.3.1 *Computer colour matching system*

The B50:C50 shows higher K/S value than B40:C60 blend and the B40:C60 shows lower K/S value than B50:C50.

5.3.2 ***Advanced crock meter (test for dyed)***
Both the blended sample possess a good and similar color fastness.

5.4 Natural printed fabric testing
5.4.1 ***Advanced crock meter (test for printed)***
Both the blended sample have a good and similar color fastness.

6. FUTURE SCOPE

This project is an attempt to find a better sustainable fibre and how good the fibre behaves when it undergoes through natural pre- treatment, dyeing and printing process. Further, we can make a good accessories like laptop covers, mouse pads, carry bags etc.., which will act as a replacement for harmful materials like plastic bags, polyester fibre etc.,

7. CONCLUSION

The B40:C60 blend shows good results and possess a required properties. Hence, the final product will be a sustainable yoga mat product made of B40:C60 which possess a good required properties and with an aroma that calmness to the mind. And also, this product will be an eco-friendly product.

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INFLUENCE OF YARN STRUCTURE ON COMPRESSION BEHAVIOUR OF PLAIN KNITTED FABRICS

Original scientific paper
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ABSTRACT: *The compression behaviour of textile fabrics is influenced by their structure, fibre properties, and the compressibility and surface properties of yarn. Due to the limited research on how yarn twist affects the compression properties of textile fabrics, this study examined the influence of yarn twist on the compression behaviour of plain knitted fabrics. Three plain knitted fabrics were produced from cotton yarns differing in twist intensity. The knitted fabrics were subjected to successive compression-release cycles. The compression-release curves of plain knitted fabrics were analysed, allowing for the calculation of specific compression parameters, including recoverable and irrecoverable compression. Using these parameters, the non-elastic deformation components were calculated. The results indicated that varying the yarn twists, which directly influence the packing density and fibre mobility in yarns, as well as the fabric structure, allows for the adequate design of the compression behaviour of plain knitted fabrics.*

Keywords: *compressibility, yarn, twist, knitted fabric, deformation components.*

UTICAJ STRUKTURE PREĐE NA KOMPRESIONO PONAŠANJE GLATKIH PLETENINA

APSTRAKT: *Kompresiono ponašanje tekstilnih materijala uslovljeno je njihovom strukturom, svojstvima vlakana, kao i kompresibilnošću i površinskim svojstvima pređe. Usled ograničenog broja istraživanja uticaja upredenosti pređe na kompresiona svojstva tekstilnih materijala, ovo istraživanje je posvećeno upravo ispitivanju efekata upredenosti pređe na kompresiono ponašanje glatkih DL pletenina. U tu svrhu su od tri različito upredene pamučne pređe proizvedene tri glatke pletenine koje su podvrgnute uzastopnim kompresionim ciklusima. Analizirane su dobijene kompresione krive, i izračunati su specifični parametri koji opisuju kompresiju pletenina. Koristeći ove parametre, izračunate su neelastične komponente deformacije pletenina. Rezultati su pokazali da variranje upredenostsi pređe, koje direktno utiče na gustinu pakovanja i pokretljivost vlakana u*

pređi, kao i na strukturu pletenine, omogućava adekvatno projektovanje kompresionih svojstava glatkih DL pletenina.

Ključne reči: *kompresibilnost, pređa, upredenost, pletenina, komponente deformacije.*

1. INTRODUCTION

The compression behaviour of textile fabrics has long been recognized as one of the most important properties determining fabric suitability for various end-uses. In addition to the ability of a fabric to compress, the recovery from compression, known as compressional resilience, is also of considerable interest. Generally, resilience can be defined as the capability of a material to return to its original form after the removal of a deforming stress. Textile fibre and fabrics are considered as an imperfectly elastic body, since they exhibit hysteresis upon the removal of stress. This hysteresis loss arises from the friction between fibres and the viscoelastic properties of the yarns in the fabric [1]. Therefore, the deformation resulting from fabric compression may be divided into two components: immediately elastic deformation and other delayed deformation, subdivided into recoverable (viscoelastic) and irrecoverable (plastic) deformations [2].
Conventional textile fabrics experience many repeated stresses and removals during their lifetime. Therefore, they should be capable of absorbing energy imparted to them during loading and releasing it upon removal of the previously applied load. The energy-absorption properties of a fabric exposed to compression cycles are a function of its load-thickness characteristics. The interaction of fibre and yarn parameters with the structural properties of the fabric contributes to energy absorption and return during multi-cycling compression. This study investigated the influence of yarn structure on the compression behaviour of knitted fabrics using the concept of energy. Although investigations have shown that changing yarn parameters such as twist, fineness, bulk, finishing treatments, etc., affect the compressional behaviour of textile fabrics, a limited number of such studies are available. Majumdar and Pol have shown that the compressibility of woven fabrics can increase with increased hairiness and decreased packing density of yarn [3]. In the study conducted by Kim and Kim [4], yarn spinning techniques (ring, compact, and air-vortex) influenced the compression behaviour of single jersey knitted fabrics by influencing surface geometry (hairiness) and packing density of yarns, ranging from the least compressible air-vortex, to the most compressible cotton yarn. Parallel bundles in the core of the air-vortex yarn caused slight rigidity under lateral compression. A more regular structure of the compact yarn, with a less hairy surface, made it less compressible than the ring yarn. Zhang et al. produced Siro false twist yarn (SFTY) by introducing two false twisters into the spinning zone. The knitted fabrics made from SFTY and conventional Siro spun yarns were compared in terms of comfort properties, indicating better compressibility and superior softness of the former knit [5]. Banale and Chattopadhyay modified cotton yarns by the de-twisting method, which caused an 8% increase in 23 tex yarn compression rate and about a 5% increase in 15 tex compression rates [6]. This yarn modification has increased the

thickness and compressibility of the single jersey knitted fabrics made therefrom. Stankovic and Bizjak indicated that using two-folded yarn can increase the compressibility of the single jersey knitted fabric [7]. Although yarn twist is a fundamental parameter in textile material design, only two studies have examined its impact on the compressibility of these materials. Atalie et al. investigated the influence of weft yarn twist on woven cotton fabrics' mechanical and sensorial comfort, indicating that an increase in yarn twist led to less compressibility of the fabric [8]. Assefa and Govindan investigated the influence of the twist factor of yarn on the sensorial comfort of single jersey knitted fabrics, showing that fabric produced from low-twisted yarn was more compressible and had higher compressional resiliency compared to the fabric from higher-twisted yarn [9]. This shortage of results prompted us to explore how yarn twist affects the compressibility of plain knitted fabrics.

2. MATERIALS AND METHODS

From three 50 tex yarns, which were produced by rotor (open-end, OE) spinning technique, with the same cotton fibre and different twist levels, three plain weft knitted fabrics were produced on a circular knitting machine under the same knitting conditions to obtain identical structure. The structural properties of the yarns and knits are presented in Tab. 1.

Table 1: Structural properties of the cotton yarns and plain knitted fabrics

Sample	Yarn		Knitted fabric (wet relaxed)		
	Factual linear density, tex	Twist, t/m	Stitch density, cm^{-2}	Thickness, mm	Mass, g/m^2
KCo1	48.94	490	82.8	1.248	446.2
KCo2	48.08	590	85.0	1.256	453.0
KCo3	49.06	690	85.5	1.268	458.8

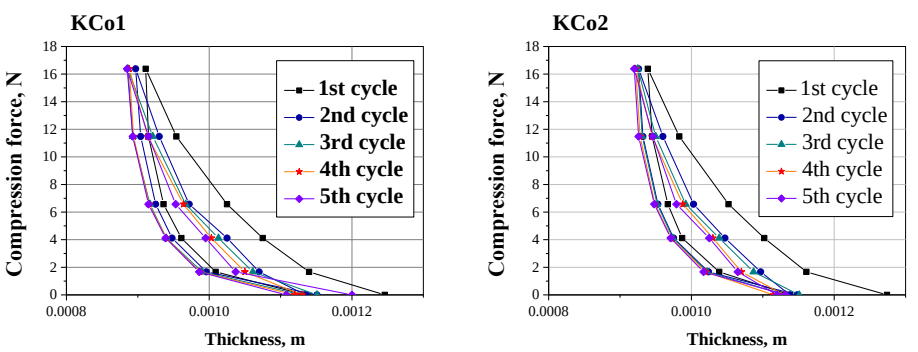
The wet relaxed plain cotton knitted fabrics were subjected to compression-release cycles by using the hand-operating thickness tester (TexTesT-306). The compression test was as follows: a piece of fabric was placed between a specimen table and a circular pressure foot having an area of 64 mm^2. Thickness measurements were made over a pressure range of 0.45-2560 cN/cm^2 with the progressively increased compression force stages: 1.7, 4.1, 6.6, 11.5, and 16.4 N. When the maximum load was reached, the recovery of the sample was conducted at successively decreasing loads. The measurements for every sample were completed in five compression-release cycles without moving the sample. Each knitted fabric was investigated by making three separate tests described on different portions of the knit, so each thickness measurement was the average of these three tests. The sample thickness measured under initial force (0.29 N) was recorded as the original sample thickness without added load. The difference in initial sample thickness (t_0) and its final thickness after the fabric was compressed (t_f) determined the compressibility of the knits for each compression cycle:

$$C(\%) = \frac{t_0 - t_f}{t_0} \times 100 \quad (1)$$

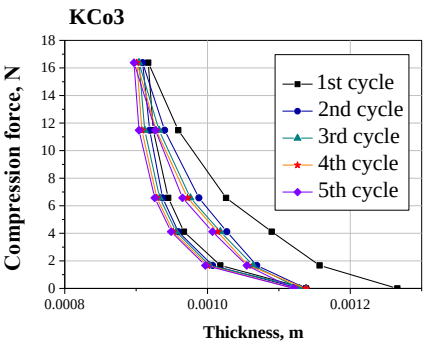
Energy-absorption properties of the knitted fabrics were evaluated from the compression-release curves by calculating the area bellow the compression curve as indication of work done or energy absorbed by the fabric (WC_{tot}), the area bellow the decompression curve indicating the energy released upon removal of the compression load (WC_{el}) and the area occupied by the hysteresis loop as a measure of non-elastic compression work or the energy lost (WC).

3. RESULTS AND DISCUSSION

The registered corresponding changes in thickness with stepwise loading and unloading provided the information necessary for the compression-release curves of the plain cotton knitted fabrics differing in yarn twist. It can be seen from the compression/release curves for five successive cycles, presented in Figure 1, that considerable changes in the fabric thickness are obvious between the first and the second cycle. Furthermore, the second cycle resulted in a hysteresis loop with entirely different characteristics, while the loops approach each other more closely with repeated cycling. What is striking is the fact that the knitted fabrics underwent both elastic and delayed deformation to a great extent during the first compression cycle. As a result of the dynamic inter-fibre friction, the irrecoverable fibre slippage and rearrangement occur to some extent, causing a highly packed fibre assembly to become larger. In a densely packed assembly, only lateral compression of the fibres is possible, resulting in a slight reduction in fabric thickness. With each subsequent compression cycle, the changes in thickness decreased.



a) b)



c)

Figure 1: Compression-release curves for five successive cycles of KCo1 (a), KCo2 (b) and KCo3 (c) knitted fabrics

The compressibility of the plain cotton knitted fabrics for repeated compression cycles is presented in Table 2. The knitted fabric produced with the highest twisted cotton yarn (Co3) has higher compressibility in relation to KCo1 and KCo2 knits for the first compression cycle. In principle, an increase in yarn twist should lead to a decrease in yarn bulk (increase in packing density) and a consequent reduction in the fabric compressibility, and therefore, the results obtained were unexpected. At least two elements were in opposition here: yarn geometry and fabric structure. Although the plain knitted fabrics were prepared under the same conditions, slight differences were found in the basic structural properties after wet relaxation (Table 1), caused by the different twist levels of the yarns. The increased stitch density of KCo2 and KCo3 knits resulted from the distortion caused by the residual torque in the yarns due to higher twist. An increase in the number of yarn contact points with an increase in stitch density reduces the inter-yarn and inter-fibre mobility, so a reduction of compressibility may be expected. However, the compressibility of KCo3 knit is higher than that of KCo1 knit (Table 2). In our speculation, the explanation is based on an inverse relationship between the yarn flattening (when incorporated into a fabric) and the twist level. The distortion from the circularity of yarn cross-section at interlocking points of knit is smaller for a highly twisted yarn. Therefore, it can be assumed that the lowest- and medium-twisted cotton yarns spent their compression ability by flattening at interlocking points to a higher extent compared to KCo3 knit. The compression forces applied during the compression cycling in this experiment (up to 2560 cN/cm^2) appear sufficient to move fibres in Co3 yarn against their static frictional force, despite their high packing density. The Co2 yarn flattening effect and the structure of KCo2 knit (stitch density) act synergistically, resulting in reduced fibre mobility and knit compressibility compared to the other two knits, during repeated compression cycles (Table 2).

Table 2: Compressibility of the cotton knitted fabrics

Sample no.	C, %				
	1st cycle	2nd cycle	3rd cycle	4th cycle	5th cycle
KCo1	26.9	21.0	23.0	21.4	20.1
KCo2	26.3	18.6	19.4	18.6	17.5
KCo3	27.6	20.3	19.9	20.8	20.5

The shift to the left from the first compression-release curve, as well as the reduction of the hysteresis loop area with repeated cycling (Figure 1), indicate a kind of mechanical conditioning (minimal thickness change). Due to the irrecoverable deformation at the previous compression cycles, the knitted fabrics become less compressible, but the non-elastic deformation also decreases. The energy-absorbing properties of the plain cotton knitted fabrics presented in Table 3 are a quantitative indication of their repeated compression stress performance. Slight differences may be noted in the energy stored up as potential energy (WC_{tot}), as well as the energy restored after recovery part of the cycle (WC_{el}), among the knitted fabrics. Even though KCo2 knit was characterized by the lowest compressibility (Table 2), the highest values of released energy (WC_{el}) in all compression cycles indicated a higher proportion of elastic deformation than other knits (Table 3). A certain amount of variability among knitted fabrics is observed for the energy lost (WC) for repeated cycles, except for the first cycle. With each subsequent cycle, the energy dissipated decreases at varying rates for different samples. As a consequence, after similar dissipated energy (WC) in the first compression cycle, the dissipation of energy in the 4th and 5th cycles was the lowest for KCo2 knit (Table 3).

Table 3: Energy-absorbing properties of the plain cotton knitted fabrics

Property	Sample	1st cycle	2nd cycle	3rd cycle	4th cycle	5th cycle
Energy absorbed $WC_{tot}\times10^{-4}$ J	KCo1	167.08	160.02	158.78	157.73	157.42
	KCo2	171.51	164.46	163.25	162.04	161.40
	KCo3	168.40	161.44	160.09	159.50	158.74
Energy released $WC_{el}\times10^{-4}$ J	KCo1	155.47	153.73	152.14	152.05	151.75
	KCo2	160.05	158.06	157.75	157.19	157.06
	KCo3	156.75	155.52	154.82	154.11	153.57
Energy dissipated $WC\times10^{-4}$ J	KCo1	11.61	6.28	6.64	5.67	5.67
	KCo2	11.46	6.40	5.49	4.85	4.33
	KCo3	11.64	5.93	5.26	5.39	5.17

Since the energy dissipation is governed by delayed deformation (viscoelastic and plastic), the particular procedure, described elsewhere [2, 10], was performed to calculate the percentage of both plastic (D_p) and viscoelastic (D_{ve}) deformation components (Table 4). According to the data given in Table 4, the viscoelastic deformation is higher than the plastic deformation for all knitted fabrics. However, the values of deformation components were almost equal for KCo2 and KCo3 knitted fabrics, whereas the viscoelastic deformation of KCo1 knitted fabric was higher than the other two knits. This can be

attributed to the greater fibre mobility in the least twisted cotton yarn and the lowest stitch density of this knit.

Table 4: Compression behaviour of the plain cotton knitted fabrics

Sample no.	$WC^{a)}$, x10^{-4} J (1+2+3+4+5)	$WC_p^{b)}$, x10^{-4} J (1-5)	$WC_{ve}^{c)}$, x10^{-4} J	$D_p^{d)}$, %	$D_{ve}^{e)}$, %
KCo1	35.87	15.33	20.54	42.74	57.26
KCo2	32.53	14.45	18.08	44.42	55.58
KCo3	33.39	14.83	18.56	44.41	55.59

a) The total energy absorbed at repeated cycles, b) the energy lost due to irreversible deformation or the irreversible work of five-cycle compression, c) the energy or the reversible compression work of five-cycle compression, d) the percentage of plastic, and e) the percentage of viscoelastic deformation

The energy-absorbing properties (Table 3) and the calculated percentages of delayed deformation components (Table 4) enabled a determination of the shares of deformation components in the total five-cycle compression. The values presented in Table 5 indicated that the deformation components (elastic, viscoelastic, and plastic) were equally present in all knitted fabrics in the first compression cycle. Starting from the third cycle, the proportion of delayed deformation components (viscoelastic and plastic) in KCo2 and KCo3 knits exhibited a steeper decreasing trend compared to KCo1 knit. With further compression cycling, a reduction in the shares of delayed deformations was most pronounced in KCo2 knit. In addition, the share of the elastic deformation (the compression resilience) was the highest in KCo2 knit after the five-cycle compression. These results indicated better retention ability of KCo2 knit after compression.

Table 5: Shares of deformation components in total compression of the plain cotton knitted fabrics

Cycle no.	KCo1			KCo2			KCo3		
	d_{el} a), (%)	d_{ve} b), (%)	d_p c), (%)	d_{el}, (%)	d_{ve}, (%)	d_p, (%)	d_{el}, (%)	d_{ve}, (%)	d_p, (%)
1st	93.05	3.98	2.97	93.32	3.71	2.97	93.08	3.85	3.07
2nd	96.07	2.25	1.68	96.11	2.16	1.73	96.33	2.04	1.63
3rd	95.82	2.39	1.79	96.63	1.87	1.5	96.71	1.83	1.46
4th	96.4	2.06	1.54	97	1.67	1.33	96.62	1.88	1.5
5th	96.4	2.06	1.54	97.31	1.49	1.2	96.74	1.81	1.45

a) Share of elastic deformation, b) share of viscoelastic deformation, c) share of plastic deformation

3. CONCLUSION

This research presents the compression behaviour of plain knitted fabrics produced from various twisted cotton yarns. Compression of knitted fabrics is the result of a complex interaction of many factors resulting from the geometry of the yarn and the fabric structure. Since both the yarn geometry and fabric structure were designed by twist intensity of yarn, it can be concluded that yarn twist significantly influences the compressibility properties of knitted fabrics. Careful analysis based upon the energy-absorption properties enables the

determination of the deformation components at compression of the knitted fabrics. This indicates that, in addition to compressibility, the yarn twist influences the mechanical conditioning of the knitted fabrics during cycled compression.

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WASTE SILKWORM COCOON-BASED COMPOSITE COATING FOR PASSIVE RADIATIVE COOLING

Original scientific paper
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ABSTRACT: *Personal thermal management technologies based on passive radiative cooling materials has attracted attention thanks to the great potential in reducing energy consumption with low carbon emission. Today, endowing common fabrics with radiative cooling capability especially using simple/scalable production method and also renewable and degradable radiative cooling materials, is an effective strategy. In this study, viscose (CV) nonwoven fabrics were coated by silk fibroin (SF) particles-based composite having high mid- infrared emissivity and solar reflectance, from waste silkworm cocoons through simple spraying method. Besides SEM and FT-IR analysis, solar reflectance and passive cooling performance under simulated conditions were measured by UV-VIS-NIR spectrometer integrated with a diffuse integrating sphere and self-made hotplate system, respectively. Also, wearability performance of the fabrics was determined by measuring physical, mechanical, and permeability performance. Coated especially SF composite coated CV fabrics enable the achievement of cooling performance with an average temperature drop of 6.4°C and 20.22°C, respectively compared to reference and bare skin as a result of high infrared emittance arising from abundant chemical bonds and also solar reflectance around 69.43%. Besides passive cooling performance, these coated fabrics had convenient physical, mechanical, and air permeability performance for practical usage. Thanks to combination passive cooling and wearability performance through upcycling of waste silkworm cocoons towards to SF particle, coated CV nonwoven would be a sustainable textile for passive personal thermal management.*

Keywords: *Silk fibroin, personal thermal management, passive radiative cooling, upcycling, viscose nonwoven, thermoplastic polyurethane.*

KOMPOZITNI PREMAZ NA BAZI ČAURE SVILENE BUBE ZA PASIVNO RADIJATIVNO HLAĐENJE

APSTRAKT:*Tehnologije ličnog termalnog upravljanja zasnovane na pasivnim materijalima za radijativno hlađenje privukle su pažnju zahvaljujući velikom potencijalu u smanjenju potrošnje energije uz nisku emisiju ugljenika. Danas je efikasna strategija davanje uobičajenim tkaninama mogućnosti radijativnog hlađenja, posebno korišćenjem*

jednostavnih/skalabilnih metoda proizvodnje, kao i obnovljivih i razgradivih materijala za radijativno hlađenje. U ovoj studiji, netkane tkanine od viskoze (CV) su presvučene kompozitom na bazi čestica svilenog fibroina (SF) sa visokom emisivnošću u srednjem infracrvenom zračenju i solarnom refleksijom, dobijenim iz otpadnih čaura svilene bube jednostavnim metodom prskanja. Pored SEM i FT-IR analize, solarna refleksija i performanse pasivnog hlađenja u simuliranim uslovima merene su UV-VIS-NIR spektrometrom integrisanim sa difuznom integrišućom sferom i samostalno napravljenim sistemom grejnih ploča. Takođe, performanse habanja tkanina su određene merenjem fizičkih, mehaničkih i performansi propustljivosti. Prevučene, posebno SF kompozitne CV tkanine sa prevlakom omogućavaju postizanje performansi hlađenja sa prosečnim padom temperature od 6,4◦C i 20,22◦C, respektivno, u poređenju sa referentnom i golom kožom, kao rezultat visoke infracrvene emisije koja nastaje usled obilnih hemijskih veza, a takođe i solarne refleksije oko 69,43%. Pored pasivnih performansi hlađenja, ove presvučene tkanine imale su pogodne fizičke, mehaničke i performanse propustljivosti vazduha za praktičnu upotrebu. Zahvaljujući kombinaciji pasivnog hlađenja i performansi nošenja kroz reciklažu otpadnih čaura svilene bube u SF čestice, presvučeni CV netkani materijal bio bi održivi tekstil za pasivno lično upravljanje toplotom.

Ključne reči: *Svileni fibroin, lično upravljanje toplotom, pasivno radijaciono hlađenje, reciklaža, viskozna netkana tkanina, termoplastični poliuretan.*

1. INTRODUCTION

Nowadays, next-generation textile materials providing personal thermal-moisture management with low carbon emission has attracted attention by taking into account the environmental concerns due to global warming and extreme heat weather [1]. In this manner, passive cooling textiles using common fabrics with scalable materials and methods have emerged as a promising solution owing to sustainable and energy-free cooling technologies [2]. To get efficient temperature reduction hence cooling performance, these materials should have both higher solar reflectance (0.3-2.5 μm) and mid-infrared emissivity (8-13 μm) without any energy input [1]. In this regard, many researchers have been developed numerous materials in a wide variety of forms, including inorganic materials [3], multilayer photonic crystal/coating [4, 5], inorganic/polymer hybrid composite materials [1]. On the other hand, most of these materials were manufactured using complicated and costly process which makes these materials unsuitable for large-scale production. At this point, imparting common fabrics with radiative cooling capability draws attention as a high potential solution method in recent years [6] by applying mid-infrared emissive polymers and/or solar reflective particles. However, using of harmful organic solvents and also complex process restricts the use of these materials. Lately, some natural polymers, including cellulose [7] and silk [6] have gained popularity for developing environmentally friendly passive cooling materials.

Silk provides an alternative sustainable option for developing passive radiative cooling materials with its higher mid-infrared emissivity arising from protein backbone (i.e., amide

groups) of SF protein and also solar reflectance as well as low cost and biodegradability [1, 6]. SF-based passive cooling materials could be developed using electrospinning [8-10] and imparting to common fabric by coating method [6]. In this study, the potential of upcycling of waste silkworm cocoons towards to SF particle and using as composite coating with thermoplastic polyurethane (TPU) polymer onto common CV nonwoven fabric through simples spraying method to impart passive cooling based thermal management.

2. MATERIALS and METHODS

2.1. Materials

CV nonwoven fabric (Spunlace, 65 g/m^2, 0.6 mm, Mogul Tekstil, Türkiye) which a kind of renewable cellulose having good breathability, dyeability, and smooth features. Waste silkworm cocoons were provided from Umurbey Silk Production and Design Center in Bursa, Türkiye. Sodium carbonate (Na_2CO_3) (ZAG Chemical, Türkiye), anhydrous calcium chloride ($CaCl_2$) (Merck, Germany), and ethanol (EtOH) (Merck, Germany) were used without purification for fibroin extraction. TPU pellets (Elastollan 1185A) were supplied by BASF Co., Ltd. N, N-Dimethylformamide (DMF) (Merck, Germany) and acetone (Merck, Germany) were as solvent and co-solvent, respectively. All chemicals and materials were used as received without further purification.

2.2. Silk fibroin extraction and particle preparation

To prepare SF particles from waste silkworm cocoon, firstly silk cocoons were broken into pieces and cleaned from the dead silkworm residues. Afterwards, the cleaned silkworm cocoon shells were boiled in 0.5 wt.% Na_2CO_3 solutions at 95°C for 1 h (liquor ratio: 70:1) to extract sericin, to remove the sericin, followed by separating the silk fiber through washing in deionized water at 60°C for three times and drying at 50°C. For the preparation of SF particles, the degummed silk fibers were dissolved in $CaCl_2$:EtOH:H_2O solution with a molar ratio of 1:2:8 at 60°C for 6 h. Finally, the obtained dispersions of SF particles were centrifuged at 10.000 rpm for 15 min and samples were previously freeze-dried at -80°C and lyophilized at - 55°C for 72 h (Labconco Centrivap Micro IR). The obtained particles milled into micrometer diameter by milling into powder using a micro powder pulveriser (Fritsch Pulverisette, Germany), then sieved through a 40 µm sieve. These SF microparticles were kept at 4°C until using.

2.3. Preparation of silk fibroin composite coated fabrics

The coated fabrics were prepared by simple spraying and drying process using CV nonwoven fabrics and TPU-SF particle solutions. For TPU and also TPU-SF coating solutions, firstly, a 10 wt.% TPU solution was obtained by dissolving TPU pellets in DMF: acetone binary solvent system with a ratio of 1:1 using mechanical stirrer at 60°C, 6 h, and 400 rpm. Subsequently, fibroin particles at a rate of 10% of the polymer was added into TPU solution and mixed mechanical stirring for another 1 h followed ultrasonic mixing for 30 min. The resulted TPU and TPU-SF composite solutions were sprayed onto the CV nonwoven fabric surface using a simple spraying system (Alfajet W-77S, Türkiye) at a pressure of about 0.3 MPa and a distance of 50 cm with a solution amount of 0.01 mL/cm^2. At last, coated fabrics were dried at room temperature for 24 h. The samples were coded as

CV (reference), CV-TPU (TPU coated ones), and CV-TPU-SF (TPU-SF composite coated ones).

2.4. Characterizations

Scanning electron microscopy (SEM) was conducted with a Fei Quanta FEG 250 instrument at an acceleration voltage of 20 kV, 10 µA current, and 500-1000 magnification for observing surface morphology of the refence and coated CV fabrics. Fourier transform infrared (FT-IR) spectra were recorded using a JASCO FT/IR 4700 spectrometer equipped with a diamond ATR (Attenuated total reflectance) in the 400-4000 cm^{-1} range, 2 cm^{-1} resolution, and 16 scan at room temperature. Also, spectral solar reflectance and transmissivity of the samples in the wavelength range of 190-2700 nm were recorded on a UV-VIS-NIR spectrometer (JASCO V-770 UV-Vis-NIR) integrated with a diffuse integrating sphere. The average values of solar reflectance were calculated according to Equations (1).

$$\bar{\rho}_{solar} = \frac{\int_{0.3\ \mu m}^{2.5\ \mu m} I_{solar}(\lambda)\cdot\rho(\lambda)d\lambda}{\int_{0.3\ \mu m}^{2.5\mu m} I_{solar}(\lambda)d\lambda} \quad (1)$$

Passive cooling performance under indoor simulation of the samples was determined by recording the temperature changing of the lower surface of the samples using a self-made hotplate system simulating skin with heating sheet, 8 K-type sensors, a sun simulator halogen lamp (600 W m^{-2}), and a data acquisition system. After 1 min stabilizing period, temperature data for cooling performance of the samples placed on the hot plate under lamp' switched-on and switched-off period for 30 min, respectively via recording one data per ten second. The average temperature variation on the lower surface of the sample were determined by performing least three replications for each sample.

A universal material tensile tester (Llyod Instruments LR5K+) was used to determine mechanical properties of the reference and coated fabric with test length and speed of 75 mm and 100 mm/min in uniaxial tests mode according to ASTM D5035-95 (2003) standard method. Moreover, physical (weight) properties were determined according to ASTM D3776/D3776M-20 to evaluate coating effect. Air permeability of the fabrics was tested using a FX Textest 3300 (James Heal Corp., UK) automatic fabric permeability meter according to TS 391 EN ISO 9237 standard under 200 Pa pressure with at least ten replicates. All test results were statistically evaluated by SPSS 26 for Windows statistical software (IBM, Armonk, USA) using Tukey post hoc test. *p* value less than 0.05 was deemed to be significant for all test results.

3. RESULTS

In this study, the potential of obtaining SF particles from waste silk cocoons and using as coating material to endow common CV nonwoven fabric with passive radiative cooling performance due to the high infrared emittance and solar reflectance characteristic, were investigated. Microstructure and also surface morphology of the reference as well as coated

CV nonwoven fabrics with TPU and TPU-SF composite, were visualized using SEM analysis and images were shown in Figure 1. As seen in Figure 1 (a_1) and (a_2), the reference CV nonwoven fabric had a smooth, porous, and open network structure with fiber entanglement. TPU and especially TPU-SF composite coating resulted in rougher surface structure, which can be seen in Figure 1 (b_1)-(b_2) and (c_1)-(c_2), respectively. Through surface coating of the CV fabrics by simple spraying method, TPU solution formed very thin and more blurred coating while TPU-SF particle composite solutions created more thicker coating on the fabric surface and among fiber/yarns. Also, there are many bright spots on the surface of the CV-TPU-SF ones owing to SF particles. SF particles and particle agglomeration resulted in rougher surface can be seen in surface of CV-TPU-SF ones (Figure 1 (c_1)-(c_2)). More rougher surface structure in coated especially TPU-SF composite coated samples could allow sunlight reflection and mid-infrared emission thereby passive cooling based thermal management.

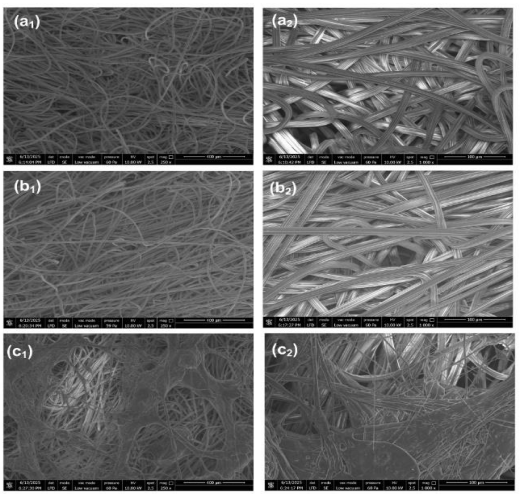

Figure 1: Surface SEM images of the reference CV (a_1)-(a_2), CV-TPU (b_1)-(b_2), CV-TPU-SF (c_1)-(c_2) at 250x and 1000x magnification

In order to evaluate molecular structure and also molecular vibration-based selective mid-infrared wavelength emission inside the atmospheric transparency window, the functional groups of the samples were analyzed using FT-IR spectra. Based on Kirchhoff's Law of thermal radiation, materials which have molecular vibration overlapping the atmospheric transparency window (8-13 μm) corresponded exactly to the absorption at 1250-780 cm^{-1}, could exhibit selective mid-infrared emission hence passive cooling performance. As seen in Figure 2, the stretching vibrations of the N-H bond, alkene-CH stretching vibrations, and C–O–C stretching vibrations were detected at 3578-3348 cm^{-1}, 2922 and 2855 cm^{-1}, and 1074 cm^{-1} which are characteristic peak of TPU. In addition to these peaks, TPU polymer had two characteristic peaks at 1731 and 1701 cm^{-1} are attributed to the free C=O and H-bonded C-O, in turn. The characteristic peak of SF particle such as amide I, amide II, and amide III were observed at 1651-1593, 1535, and 1233 cm^{-1}, arising from C-N stretching,

C-N and N-H deformation, respectively [11, 12]. Also, characteristic peak of polypeptide corresponding to peptide bands were observed in the range 800-1200 cm^{-1}. -OH of alcoholic and carboxylic and -C = O bands were represented at 3200-3500 and 1655 cm^{-1} in the IR spectrum of the reference CV fabrics. The coated especially TPU-SF composite coated samples exhibit strong infrared absorption due to the mentioned molecular vibration peaks overlapping the atmospheric transparency window contribute to higher thermal emittance thereby passive cooling performance.

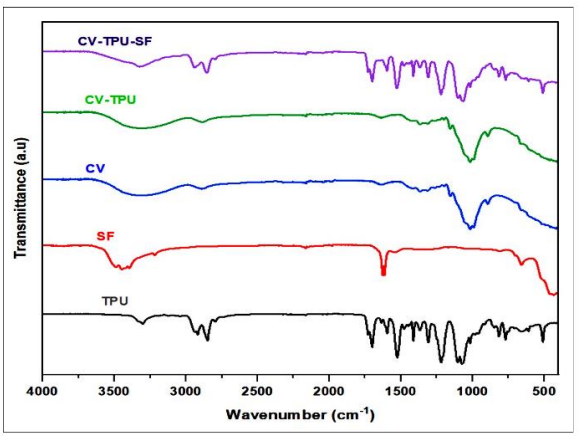

Figure 2: FT-IR spectra of TPU polymer, SF particle, reference and coated CV fabrics

High solar reflectance and also emissivity from atmospheric windows are fundamental parameters for achieve efficient passive cooling performance in outdoor thermal management. In order to evaluate solar reflectance performance of the samples, solar reflectance spectra of the samples in corresponding wavelength were measured and average solar reflectance values are calculated. As shown in Figure 3, TPU and TPU-SF composite coating enhances the solar reflectance of the CV nonwoven fabric. The reference CV nonwoven samples showed an average reflectance of 51.23% as this value increased with TPU and reached up to maximum value of 69.43% in CV-TPU-SF ones. Rougher surface and also SF particles on the fabric surface as seen in related SEM images resulted in sufficient reflection and Mie scattering of sunlight [1, 6]. The average solar reflectance value obtained through coating especially including SF particles is consistent with similar study about coating of cotton fabric with only SF particles [6]. These results indicate that SF particles have enhanced solar reflectance and mid-infrared emissivity hence passive radiative cooling performance.

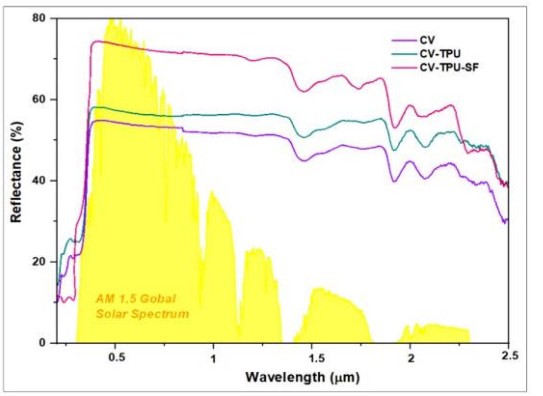

Figure 3: Solar reflectance spectrum of the reference and coated CV fabrics

Passive cooling performance of the samples were measured using a designed hotplate system with heating sheet which simulating human MIR emission, 8 K-type sensors for recording the real-time temperature of the samples, halogen lamp (600 W m^{-2}) simulating sunlight exposure, and a data acquisition system. Real time temperature graphic and also temperature variation of the samples between each other and also bare skin are given in Figure 4, Table 1, and Table 2, respectively. As seen in Figure 4 and Table 2, the temperature of the all samples gradually increased and reached maximum for each sample after 30 min of sunlight exposure. Thanks to the higher solar reflectance and mid-infrared radiation emission, CV-TPU-SF samples finally displayed a temperature of 49.86°C, lower than the all other fabric samples (54.1°C and 56.28°C for CV-TPU and reference CV, respectively) and also bare skin (70.08°C). Under a solar intensity of 600 W m^{-2}, passive cooling effect were detected for TPU and TPU-SF composite coating with a temperature drop of 2.18 and 6.41°C (Table 1), in turn compared to reference ones. Compared to smooth fiber surface in reference fabrics, rougher fiber surface in TPU and TPU-SF composite coated ones as seen in SEM images resulted in higher solar reflection and Mie scattering hence passive cooling performance. Although, the average reflectance values of the TPU and TPU-SF composite coated samples are close, the temperature drop, hence the cooling effect enhanced with SF particle up to 6.41°C thanks to higher mid-infrared emission based on strong molecular vibration peaks such as amide I, amide II, and amide III arising from N-H, C=O, and C-O in SF molecules [6, 8] overlapping the atmospheric transparency window (as seen in FT-IR spectra) as well as solar reflectance. The same samples exhibited lower temperature by an average of 20.22°C as compared to the bare skin simulating the body without clothing under simulated conditions, which is higher than differences of reference and TPU coated samples from bare skin with lower temperature value of 13.80°C and 15.98°C (Table 1), respectively. The temperature drop obtained in the mentioned sample is higher than the studies using SF particles for thermal management [6, 8]. In a passive radiative cooling material, the minimum temperature increase under the lamp simulating solar (ΔT_{solar}) is targeted, while the maximum temperature decrease (ΔT_{shadow}) after the lamp is turned off is the ideal situation for it to cool down as quickly as possible. As seen in Table 2, CV-TPU-SF samples had the minimum ΔT_{solar} and maximum ΔT_{shadow}

with value of 16.36 and 49.86, respectively as well as lower temperature values. These results indicate that coated fabrics especially with TPU-SF composite have enhanced solar reflectance and mid-infrared emission, which is beneficial for personal thermal management through passive radiative cooling.

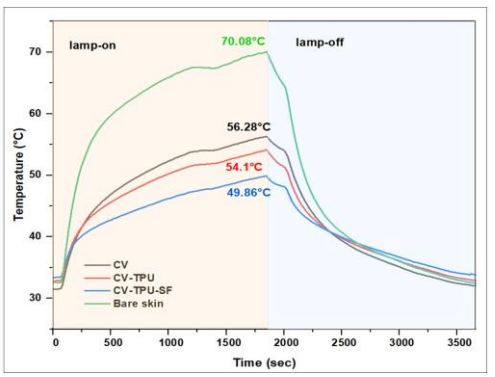

Figure 4: Real-time temperature curves of the films and bare skin.

Table 1: Comparative cooling performances of the reference and coated CV fabrics

ΔT_{max} (°C)		
1-2	**1-3**	**2-3**
2.18	6.41	4.24
Bare skin-fabric samples		
13.80	15.98	20.22

*1: Reference CV nonwoven, 2: CV-TPU, 3: CV-TPU-SF

Table 2: Temperature changes of the reference and coated CV fabrics under sunlight exposure and shadow

Sample	ΔT_{max} (°C)			
	CV	**CV-TPU**	**CV-TPU-SF**	**Bare skin**
T_0	31.54	32.87	33.46	32.51
$T_{maximum}$	56.27	54.10	49.86	70.08
ΔT_{solar}	24.67	21.16	16.36	34.43
T_{end}	32.03	32.89	33.83	32.47
ΔT_{shadow}	56.53	54.04	49.86	69.94

To evaluate wearability performance of the samples in practical applications as a clothing or medical textile materials; physical, mechanical, and permeability tests were conducted. Weight (physical) values and mechanical properties of the reference and coated CV fabrics were given in Table 3. According values in Table 3, TPU and TPU-SF composite coating

resulted in significantly (p=0<0.05) weight increasing and the maximum values belonged to the coated samples with TPU-SF composite coating. Conversly, the coating type such as TPU or TPU-SF composite ones did not effect sample weight. Mechanical performance such as tensile stress-strain properties were examined and the effect of coating with TPU and TPU-SF composite was summarized in Table 3 and Figure 5, respectively. As shown in Table 3 and Figure 5(a), the tensile strength values of the samples in both direction increased significantly via TPU and TPU-SF composite coating. In MD, the maximum tensile strength values belonged to CV-TPU-SNF samples with 92.76 N while for CD direction this value was was 21.45 N and belonged to CV-TPU ones. In both direction, the minimum tensile strength values detected in reference CV ones. TPU and TPU-SF composite coating increased the mechanical strength of the samples by chemical interaction of hydroxyl on the amino acid of the SF molecular chain with the amino (-NH) from TPU as seen in FT-IR spectrum. Also, strong interfacial interaction with fabric surface by developing more hydrogen bonds with the TPU matrix due to the hydroxyl groups in SF particle structures enhanced the mechanical properties. On the other hand, elongation values at break reduced with TPU while increased with TPU-SF composite coating in the both direction as compared to the reference CV samples (Figure 5(b)). Consequently, the resulting composite fabrics coated with TPU and TPU-SF composite, had convenient mechanical performances.

Table 3: Physical and mechanical properties of the efference and coated CV nonwoven fabrics

Sample	Weight (g/m^2) [S.D]	Tensile strength, MD (N) [S.D]	Tensile strength, CD (N) [S.D]	Elongation, MD (%) [S.D]	Elongation, CD (%) [S.D]
CV	64.96^a [1.69]	64.06^a [2.44]	15.11^a [0.84]	17.22^b [0.89]	86.62^{ab} [3.42]
CV-TPU	79.34^b [0.94]	69.92^b [3.74]	21.45^c [1.82]	12.36^a [0.55]	83.10^a [4.09]
CV-TPU-SF	80.48^b [3.97]	92.76^c [4.55]	18.10^b [1.67]	17.88^b [2.34]	90.72^{ab} [3.35]

*: Different superscript letters show statistically significant differences

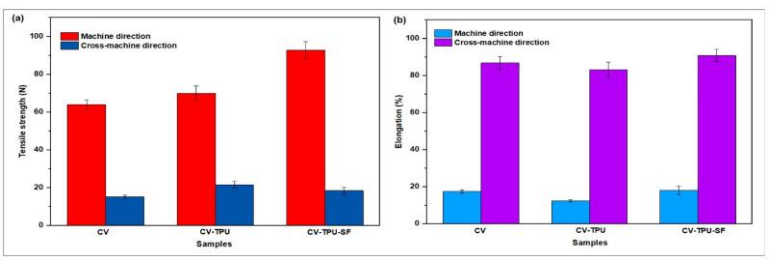

Figure 5: Mechanical properties of the reference and coated CV fabrics, tensile strength (a) and elongation values (b) at break.

As an another parameter of wearability and also permeability, air permeability of the samples evaluated and results were shown in Figure 6. As seen in Figure 6, air pemeability

performance of the CV nonwoven fabrics significantly reduced with TPU and TPU-SF composite coating and minimum values were determined in CV-TPU ones (1313.18 l/m^2/s) thanks to the filling pores of nonwoven fabric with TPU polymer as can be seen in SEM inmages. Although the air permeability performance decreases with the TPU-SF composite coating, it is higher than TPU coated ones with value of 1618.64 l/m^2/s. Based on the values and performance metrics, it can be drawn that the physical, mechanical property, and air permeability of the CV nonwoven fabrics were found to be affected by TPU and TPU-SF composite coating owing to the filling of some interspaces between fibers by the coating.

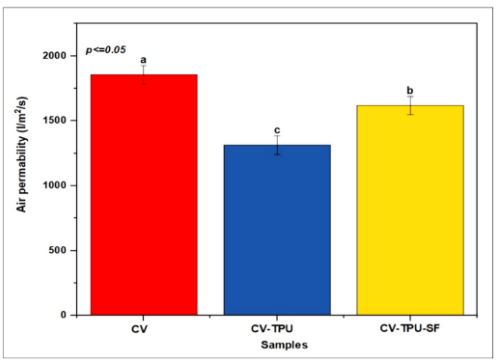

Figure 6: Air permeability of the reference and coated CV nonwoven fabrics.

4. CONCLUSION

In summary, eco-friendly passive radiative cooling fabrics are developed by coating of the CV nonwoven fabrics using TPU polymer and SF particles regenerated from waste silkworm cocoons, through simple spraying method for thermal management. Owing to advantages of the high infrared emittance and also solar reflectance of the SF particles, coated especially TPU-SF composite coated CV fabrics enables the achievement of cooling performance with an average temperature drop of 6.4˚C and 20.22˚C, respectively compared to reference and bare skin under simulated condition using 600 Wm^{-2} solar irradiance. Also, TPU-SF composite coated CV fabrics had convenient mechanical and breathability performances ensuring its potential for applications in the field of personal thermal management. Besides its passive cooling performance and wearability features, upcycling of waste silkworm cocoons towards to SF particle and also using as coating material attracts attention as a sustainable production method for passive personal thermal management.

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COLOR AND UV PROTECTION PROPERTIES OF WOOL FABRICS DYED WITH NATURAL TANNINS: VALEX, MIMOSA, AND CHESTNUT EXTRACTS

Original scientific paper
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ABSTRACT: *This study investigates the dyeing behavior of wool fabrics using natural tannin-based dyes, specifically valex, mimosa, and chestnut extracts, both individually and in combination. These bio-sourced colorants are rich in polyphenolic compounds and represent sustainable alternatives to synthetic dyes, aligning with the growing demand for environmentally friendly textile processes. Wool fabrics were dyed without the use of metal mordants to evaluate the natural affinity of these tannin-rich extracts for protein-based fibers. In addition to single-component dyeings, binary and ternary combinations of the extracts were tested to explore potential synergistic or modifying effects on color performance. Color yield (K/S values), color fastness to washing and rubbing, and ultraviolet protection properties (UPF) were evaluated for all dye formulations. Results indicated that all dye sources produced distinctive shades with acceptable fastness and varying levels of UV protection. Among the single dyes, valex provided the highest UV protection, while mimosa was less effective in enhancing the UV-blocking ability of wool. The combined formulations yielded intermediate or enhanced color characteristics, suggesting interactions among the tannins. These findings highlight the potential of both individual and blended natural extracts for eco-friendly wool dyeing, with the added functional benefit of UV protection.*

Keywords: *Wool dyeing, valex, mimosa, chestnut, UV protection, color fastness.*

BOJA I UV ZAŠTITNA SVOJSTVA VUNENIH TKANINA OBOJENIH PRIRODNIM TANINIMA: EKSTRAKTI VALEKSA, MIMOZE I KESTENA

APSTRAKT: *Ova studija istražuje ponašanje bojenja vunenih tkanina korišćenjem prirodnih boja na bazi tanina, konkretno ekstrakata valeksa, mimoze i kestena – kako pojedinačno, tako i u kombinaciji. Ovi biljnog porekla koloranti bogati su polifenolnim jedinjenjima i predstavljaju održivu alternativu sintetičkim bojama, u skladu sa sve većom potražnjom za ekološki prihvatljivim tekstilnim procesima. Vunene tkanine su bojene bez upotrebe metalnih mordanata, kako bi se procenila prirodna afinitetnost ovih ekstrakata*

bogatih taninom prema proteinima u vlaknima. Pored bojenja pojedinačnim ekstraktima, ispitivane su i binarne i ternarne kombinacije, sa ciljem da se istraže mogući sinergijski ili modifikujući efekti na bojene karakteristike. Za sve formulacije boja procenjeni su intenzitet boje (K/S vrednosti), postojanost na pranje i trljanje, kao i svojstva zaštite od ultraljubičastog zračenja (UPF). Rezultati su pokazali da su svi izvori boja proizveli prepoznatljive nijanse sa prihvatljivom postojanošću i različitim nivoima UV zaštite. Među pojedinačnim bojama, valeks je obezbedio najveću UV zaštitu, dok je mimoza bila manje efikasna u poboljšanju sposobnosti vune da blokira UV zračenje. Kombinovane formulacije dale su srednje ili poboljšane bojene karakteristike, što ukazuje na moguće interakcije između različitih vrsta tanina. Ova saznanja naglašavaju potencijal i pojedinačnih i mešanih prirodnih ekstrakata za ekološko bojenje vune, sa dodatnom funkcionalnom prednošću u vidu UV zaštite.

Ključne reči: *Bojenje vune, valeks, mimoza, kesten, UV zaštita, postojanost boje.*

1. INTRODUCTION

The increasing awareness of the environmental consequences of conventional textile processing has led to a growing demand for sustainable and eco-friendly alternatives across the industry. Among these, the use of natural dyes has regained attention as a viable solution for replacing synthetic colorants, which are often associated with toxicity, non-biodegradability, and harmful effluents [1]. Historically used for centuries in traditional textile practices, natural dyes are now being reconsidered within a modern framework of circular economy and green chemistry.

One group of natural dyes that holds particular promise is tannin-based plant extracts, which are not only capable of producing color but also possess mordanting properties due to their strong affinity for protein-based fibers. Tannins, being polyphenolic in nature, can form stable complexes with wool keratin without requiring the use of metal salts, making them especially attractive in the context of metal-free dyeing [2]. Among the various plant-derived tannins, valex, mimosa, and chestnut stand out for their high tannin content and commercial availability. These extracts are traditionally used as mordants or auxiliaries in natural dyeing; however, they also impart their own distinct shades and can be considered natural dyes in their own right [2-4].

Despite the known dyeing potential of these tannin sources, studies that systematically compare their behavior under controlled conditions are limited. Even less explored is the effect of combining different tannin extracts in various proportions, which may influence not only color strength and tone but also the overall fastness properties of the dyed fabric. Furthermore, tannins are known to absorb ultraviolet radiation due to their aromatic and phenolic structure [5-7], yet their contribution to UV protection in dyed wool fabrics has received relatively little attention in the literature. Understanding the extent to which these natural dyes enhance ultraviolet protection could add a valuable functional dimension to their use.

This study aims to investigate the dyeing properties of wool fabrics using valex, mimosa, and chestnut extracts—both individually and in binary and ternary mixtures—under identical dyeing conditions. In addition to evaluating color yield (K/S values), washing and

rubbing fastness, and visual appearance, the ultraviolet protection factor (UPF) of each dyed fabric was assessed to determine the functional benefits offered by these plant-derived dyes. Wool, being a naturally proteinaceous and renewable fiber, serves as an ideal substrate to examine the behavior of tannin-based dyes. The fabrics were dyed without metal mordants to assess the natural binding capacity of each extract and their mixtures. By exploring the color and functional properties imparted by both individual and blended tannin extracts, this study contributes to the development of sustainable, metal-free dyeing strategies for wool and highlights the added value of natural dyes in eco-friendly textile coloration.

2. MATERIALS AND METHODS

2.1. Materials

The scoured and bleached 100% wool fabric, woven at a weight of 145 g/m^2, was supplied by Yünsa Inc. (Tekirdağ, Türkiye) and used as received (without any further treatment prior to the experimental part). Commercial tannin extracts (valex, mimosa, and chestnut) used in this study were obtained from AR-TU Kimya (Manisa, Türkiye) and was used without any purification. Acetic acid was purchased from Merck.

2.2. Dyeing Process

The wool fabrics were dyed using an exhaust dyeing method with natural tannin-based extracts. Three different plant-derived dyes – valex, mimosa, and chestnut – were used individually and in binary and ternary combinations. All dyeings were performed at a constant concentration of 3% o.w.f. (on the weight of fabric), either as single extracts or in equal-ratio mixtures (e.g., 1.5% + 1.5% or 1% + 1% + 1%).

The dyeing process was carried out in a laboratory dyeing machine at a liquor-to-goods ratio of 20:1. The pH of the dye bath was adjusted to 4.5–5.0 using acetic acid. Dyeing was performed at 90°C for 60 minutes. After dyeing, the samples were rinsed thoroughly with warm distilled water for 15 minutes, followed by another rinse and air drying at room temperature.

2.3. Color Measurements

Colorimetric evaluations of the dyed wool fabrics were performed using a Hunterlab Ultra Scan PRO spectrophotometer. Measurements were conducted based on the CIELAB color space system, utilizing D65 standard illuminant and a 10° standard observer angle. In this color system, L* indicates the brightness of the fabric, a* describes the red-green axis, and b* corresponds to the yellow-blue axis. From these values, chroma (C*) and hue angle (h°) were also calculated to characterize color saturation and hue.

The color strength (K/S value) of each sample was determined through reflectance measurements at the wavelength of maximum absorption (400 nm), applying the Kubelka–Munk function. This equation is expressed as:

$$K/S = \frac{(1-R)^2}{2R}$$

where *R* refers to the reflectance of the dyed fabric.

2.4. Fastness Testing

The washing fastness of the dyed wool fabrics was evaluated using a Gyrowash machine operated at 40 °C for 30 minutes. The procedure followed the ISO 105-C06 (A1S) standard, and the washing process was performed in the presence of ECE reference detergent. After washing, the samples were rinsed with water and dried at room temperature. Changes in shade and staining on adjacent fabrics were assessed using the standard grayscale method. For rubbing fastness, the ISO 105-X12 protocol was applied using a Crockmeter device. Both dry and wet rubbing tests were conducted to determine the extent of color transfer from the dyed fabric onto a white test cloth. The staining intensity was again rated by comparison to a grayscale, providing a visual scale for assessing color fastness to mechanical friction.

2.5. Ultraviolet Protection Factor Analysis

The ultraviolet protection factor (UPF) and UVR transmission (T%) properties of the dyed wool fabrics were measured using a Labsphere UV 2000F analyzer, following the AS/NZS 4399:2017 standard. Measurements were taken from four different areas on each fabric sample, and the average UPF value was calculated to ensure reliable representation of the material's UV-blocking performance.

According to the AS/NZS 4399:2017 classification, fabrics with a UPF rating of 50 or higher are considered to provide excellent protection against ultraviolet radiation. Depending on the instrument's capacity, UPF values can theoretically reach up to 2000. The categorization of UPF values based on this standard is summarized in Table 1.

Table 1: UPF rating categories and corresponding UV protection levels

Classification	UV Radiation Blocking (%)	UPF Rating
Minimum	93.3	15
Good	96.7	30
Excellent	98.0	50, 50+

3. RESULTS AND DISCUSSION

3.1. Color Properties

The colorimetric results of wool fabrics dyed with different tannin-based extracts are presented in Table 2 and visually illustrated in Figure 1. As expected, all dyed samples exhibited significant color differences compared to the undyed control, as reflected by substantial changes in L*, a*, and b* values. The fabric dyed with 3% valex showed the lowest L* value (61.43), indicating the darkest appearance among all samples, consistent with its highest K/S value (4.06). In contrast, the mimosa-dyed fabric exhibited the highest a* value (8.00), suggesting a stronger red hue component, while chestnut extract yielded the highest b* value (20.11), reflecting a more pronounced yellow tone.

Table 2: Colorimetric values of wool fabrics dyed with tannin extracts

Sample ID	L*	a*	b*	C*	h°	K/S
Undyed	86.6	-0.30	13.50	13.5	91.26	0.46
3% Valex	61.43	5.16	19.30	19.97	75.03	4.06
3% Mimosa	65.73	8.00	12.14	14.54	56.6	1.41
3% Chestnut	63.34	7.06	20.11	21.31	70.66	3.38
1.5% Valex + 1.5% Mimosa	62.40	6.55	16.26	17.53	68.07	2.82
1.5% Valex + 1.5% Chestnut	63.03	6.04	20.40	21.28	73.51	3.72
1.5% Mimosa + 1.5% Chestnut	64.54	7.64	17.16	18.78	66.01	2.42
1% Valex + 1% Mimosa + 1% Chestnut	63.02	4.33	17.39	17.92	76.01	2.91

Chroma (C*) and hue angle (h°) values further clarified the differences in color saturation and shade direction. Chestnut extract resulted in the highest C* (21.31), indicating strong color vividness. In general, binary and ternary mixtures produced intermediate color characteristics between their individual counterparts. For instance, the 1.5% Valex + 1.5% Chestnut sample showed relatively high color strength (K/S: 3.72) and saturation (C*: 21.28), demonstrating potential synergy between the two extracts. The ternary mixture (1% Valex + 1% Mimosa + 1% Chestnut) displayed a more balanced shade (h°: 76.01) and moderate K/S value (2.91), making it visually appealing despite not reaching the maximum color depth.

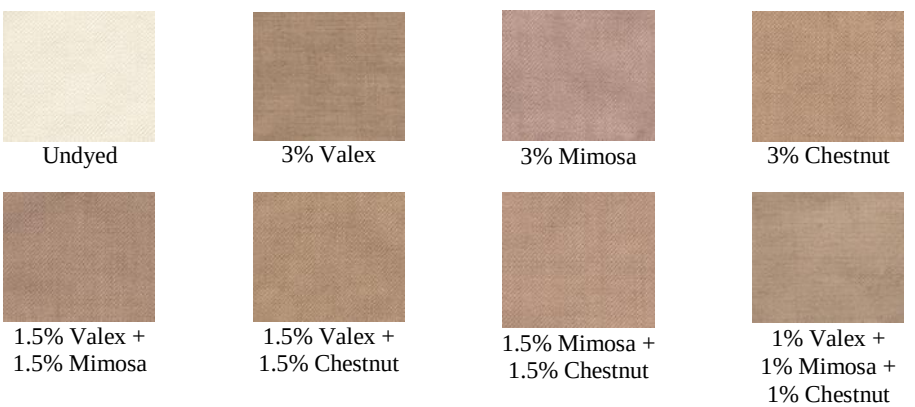

Figure 1: Visual appearance of undyed and dyed wool samples

These results confirm that not only the type of tannin extract but also the blending ratio significantly influences the color strength and tone, allowing for tunable dyeing outcomes in natural coloration of wool fabrics.

3.2. Ultraviolet Protection Properties

UPF values and UV transmittance data of the dyed wool fabrics are summarized in Table 3 and visualized in Figure 2. All dyed samples demonstrated superior UV-blocking capabilities compared to the undyed control, confirming the functional benefit of tannin-based extracts. The undyed fabric showed a UPF of 63.22, offering moderate UV protection. In contrast, fabrics dyed with valex achieved remarkably high UPF values, peaking at 1587.87, indicating nearly complete blocking of UVA and UVB rays (0.17% and 0.06% transmission, respectively).

Mimosa- and chestnut-dyed samples also exhibited significant UV protection, with UPF values of 267.54 and 783.28, respectively. Binary mixtures, such as Valex + Chestnut and Valex + Mimosa, achieved UPF ratings of 985.27 and 490.84, which fall within the "excellent protection" category as defined by the AS/NZS 4399 standard. Interestingly, the ternary mixture provided a UPF of 1116.26, suggesting a possible synergistic effect among the three extracts. This implies that combinations of tannin sources can be tailored not only for color aesthetics but also for functional UV shielding.

The reduction in UV transmission values for both UVA and UVB regions supports the hypothesis that polyphenolic compounds present in tannins contribute significantly to UV absorption. These findings reinforce the dual role of natural tannin-based dyes: providing coloration and enhancing UV protection.

Table 3: Ultraviolet Protection Factor (UPF) and transmittance of UV radiation (T%) for wool samples

Sample ID	UPF	T (UVA%)	T (UVB%)
Undyed	63.22	6.26	0.90
3% Valex	1587.87	0.17	0.06
3% Mimosa	267.54	1.66	0.20
3% Chestnut	783.28	0.44	0.10
1.5% Valex + 1.5% Mimosa	490.84	0.58	0.15
1.5% Valex + 1.5% Chestnut	985.27	0.32	0.09
1.5% Mimosa + 1.5% Chestnut	669.79	0.63	0.11
1% Valex + 1% Mimosa + 1% Chestnut	1116.26	0.47	0.06

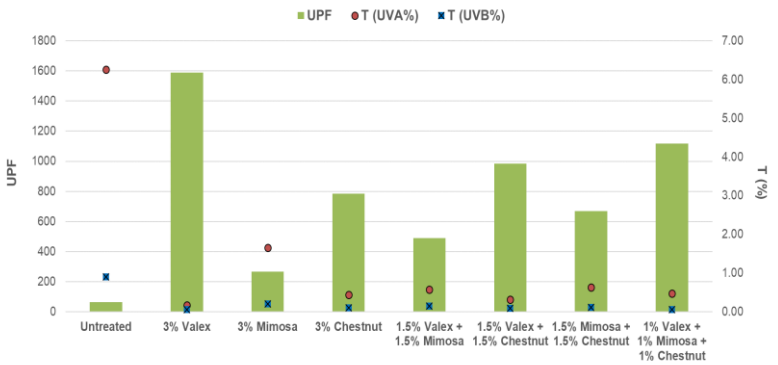

Figure 2: UPF and UV transmittance (T%) of wool samples

3.3. Fastness Properties

Fastness results presented in Table 4 indicate generally good performance for all dyed samples. Washing fastness showed no staining (grade 5) and minimal color change (4 to 5) across all formulations, confirming good fixation of tannin-based colorants to wool fibers. Rubbing fastness was also favorable, with both dry and wet tests yielding grades between 4/5 and 5.

Table 4: Fastness values of wool samples

Sample ID	Washing fastness		Rubbing fastness	
	Staining	Color change	Dry	Wet
3% Valex	5	4/5	5	4/5
3% Mimosa	5	4/5	5	5
3% Chestnut	5	3/4	5	4/5
1.5% Valex + 1.5% Mimosa	5	4/5	5	4/5
1.5% Valex + 1.5% Chestnut	5	4	5	4/5
1.5% Mimosa + 1.5% Chestnut	5	3/4	5	5
1% Valex + 1% Mimosa + 1% Chestnut	5	4/5	5	4/5

Among the individual dyes, mimosa and valex performed slightly better in rubbing fastness than chestnut. However, chestnut-containing combinations still achieved acceptable ratings. The ternary mixture displayed consistent fastness across all parameters, supporting its potential as a balanced natural dye formulation.

These results validate the application of tannin extracts as natural dyes that not only provide acceptable color fastness but also eliminate the need for metal mordants, contributing to safer and more sustainable textile processing.

4. CONCLUSION

This study demonstrated the potential of valex, mimosa, and chestnut extracts as sustainable dye sources for wool fabrics. All three extracts, both individually and in combination, produced distinct and aesthetically appealing colors with acceptable fastness properties. Valex stood out as the most effective dye in terms of color strength and UV protection, while mimosa imparted brighter tones with superior rubbing fastness.

Blending of extracts enabled intermediate and harmonious color outcomes, along with enhanced functional performance such as UV shielding. Notably, the ternary blend achieved high UPF values and good color characteristics, confirming the value of extract combinations in optimizing both appearance and function.

Overall, the findings highlight the versatility of tannin-based natural dyes in producing eco-friendly wool textiles that combine aesthetic richness with added protective features. The results provide a scientific basis for further development of multifunctional natural dyeing strategies in sustainable textile applications.

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PRINTING POISE: DIGITAL FABRICATION ON TEXTILES FOR WEARABLE POSTURE SUPPORT

Professional paper
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ABSTRACT: *This endeavor looks into the fusion of fashion, biomechanics, and digital fabrication through the creation of a posture-supporting corset. The design utilizes parametric modeling in Grasshopper™ to generate bespoke patterns, which are then 3D printed directly onto a textile surface. Expanding on existing research into the combination of additive manufacturing and textiles, the presented paper aims to assess how computational design can enhance both aesthetics and function in wearable technologies. The corset integrates decorative geometries with purposefully reinforced areas to encourage upright posture without compromising comfort. The project reimagines the corset, a historical symbol of femininity and restriction, through the lens of algorithmic design and digital fabrication. By replacing the traditional boning with generated geometries, the wearable challenges conventional narratives around body support and fashion. This contrast between past and future, softness and structure, couture and code, serves as the foundation of the design inquiry. By combining algorithmic design, personal health support, and expressive fashion, this venture demonstrates the potential of 3D printing on textiles to deliver both biomechanical benefit and visual identity. The work contributes to the growing field of functional fashion and proposes new workflows for wearable customization at the intersection of design and digital fabrication.*

Keywords: *Computational design, Wearables, 3D printing, Functional fashion.*

ŠTAMPANJE STABILNOG POLOŽAJA: DIGITALNA IZRADA TEKSTILA ZA NOSIVU PODRŠKU POLOŽAJA

APSTRAKT: *Ovaj poduhvat ispituje fuziju mode, biomehanike i digitalne izrade kroz stvaranje korseta koji podržava držanje. Dizajn koristi parametarsko modeliranje u Grasshopper™-u za generisanje prilagođenih šablona, koji se zatim 3D štampaju direktno na tekstilnu površinu. Proširujući postojeća istraživanja o kombinaciji aditivne proizvodnje i tekstila, predstavljeni rad ima za cilj da proceni kako računarski dizajn može poboljšati i estetiku i funkciju u nosivim tehnologijama. Korset integriše dekorativne geometrije sa namenskim ojačanim delovima kako bi se podstaklo uspravno držanje bez ugrožavanja udobnosti. Projekat reinterpretira korset, istorijski simbol ženstvenosti i ograničenja, kroz prizmu algoritamskog dizajna i digitalne izrade. Zamenom tradicionalnog oblikovanja generisanim geometrijama, nosivi korset dovodi u pitanje konvencionalne narative o potpori tela i modi. Ovaj kontrast između prošlosti i budućnosti, mekoće i strukture, visoke mode i koda, služi kao osnova istraživanja dizajna. Kombinovanjem algoritamskog dizajna, podrške ličnom zdravlju i ekspresivne mode, ovaj poduhvat demonstrira potencijal 3D štampanja na tekstilu da pruži i biomehaničku korist i vizuelni identitet. Rad doprinosi rastućoj oblasti funkcionalne mode i predlaže nove tokove rada za personalizaciju nosive opreme na preseku dizajna i digitalne izrade.*

Ključne reči: *Računarski dizajn, Nosivi uređaji, 3D štampanje, Funkcionalna moda.*

1. INTRODUCTION

The convergence of digital fabrication and wearable design opens new possibilities for health-supportive garments that maintain style and comfort. Traditional posture correctors are typically rigid and clinical in appearance, limiting their adoption in daily fashion. This study suggests an alternative: a flexible corset that incorporates PLA-based 3D-printed geometries onto fabric to provide postural reinforcement via generative design. The research explores computational workflows and additive manufacturing methods to create anatomically responsive and aesthetically engaging garments.

2. BACKGROUND AND RELATED WORK

2.1. Computational Workflows and 3D Printing on Textiles

Computational design tools such as Grasshopper™ have enabled the development of custom, complex garment geometries. Designers like Iris van Herpen have demonstrated the expressive potential of algorithmic fashion [1]. However, these works often prioritize aesthetics over wearability. By directly depositing polymers onto textiles, a hybrid model emerges that balances flexibility with structural integrity [2, 3].

Research has shown that materials such as PLA, ABS, and TPU can adhere to fabrics with varying success depending on textile structure, surface treatment, and print settings [3, 7]. Techniques such as plasma etching and thermal pre-treatment can enhance adhesion. Key

challenges include maintaining drape, ensuring washability, and customizing form without overcomplicating production [8, 9].

2.2. Posture Support and Functional Fashion

Posture-support wearables have been explored using both mechanical and electronic systems. However, few integrate aesthetic design and biomechanical support. Generative workflows allow user-specific adaptation and the incorporation of motifs into supportive geometry [1, 4]. This project seeks to advance this methodology by embedding structural elements directly onto garments, merging functionality and style.

2.3 Wearable Product Design and Digital Manufacturing

Minaoglou et al. (2024) present a structured review of wearable product design, emphasizing the role of computational tools, additive manufacturing, and user-centered strategies in personalized health support. Their findings highlight how 3D printing enables functional integration and ergonomic design tailored to user-specific needs [5]. Spahiu et al. (2020) demonstrate through case studies how FDM technology can be applied in fashion contexts, such as accessories, shoes, and textile structures, underscoring the value of direct digital workflows for sustainable and customizable fashion manufacturing [6].

3. METHODOLOGY

3.1. Design and Parametric Modeling

At the start of this project, a variety of potentially designed wearables were examined in the form of sketches. This exploration of concepts eventually led to the final design of the corset (Fig. 1).

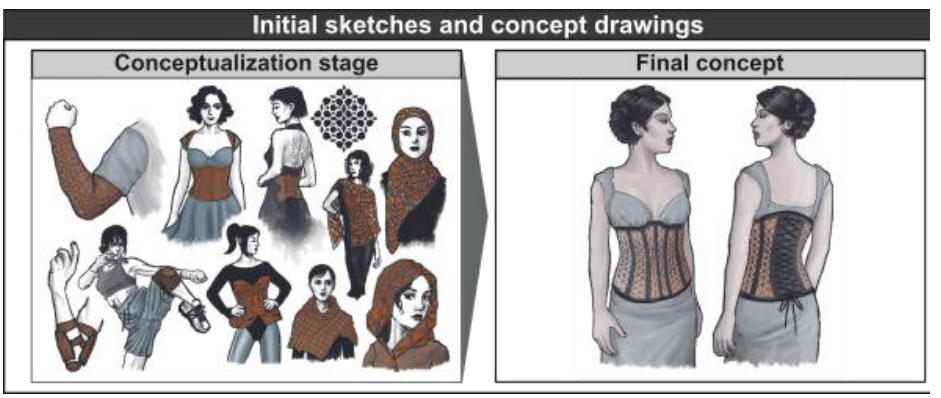

Figure 1: Initial sketches eploring corset form and posture zones

The corset was designed in Rhinoceros3D™ with a parametric script in Grasshopper™ (Fig. 2). The parametric script can be described as follows:

- Collecting user-specific body measurements (hip circumference, torso lengths, waist-hip ratio, lumbar curvature).
- Creating a 12-panel corset base pattern.
- Extracting and offsetting individual panels.
- Using the LunchBox™ plugin to generate triangle mesh patterns on each panel.
- Scaling triangles based on proximity to panel center, removing excessively small triangles.
- Mirroring panel geometry to create bilateral symmetry.

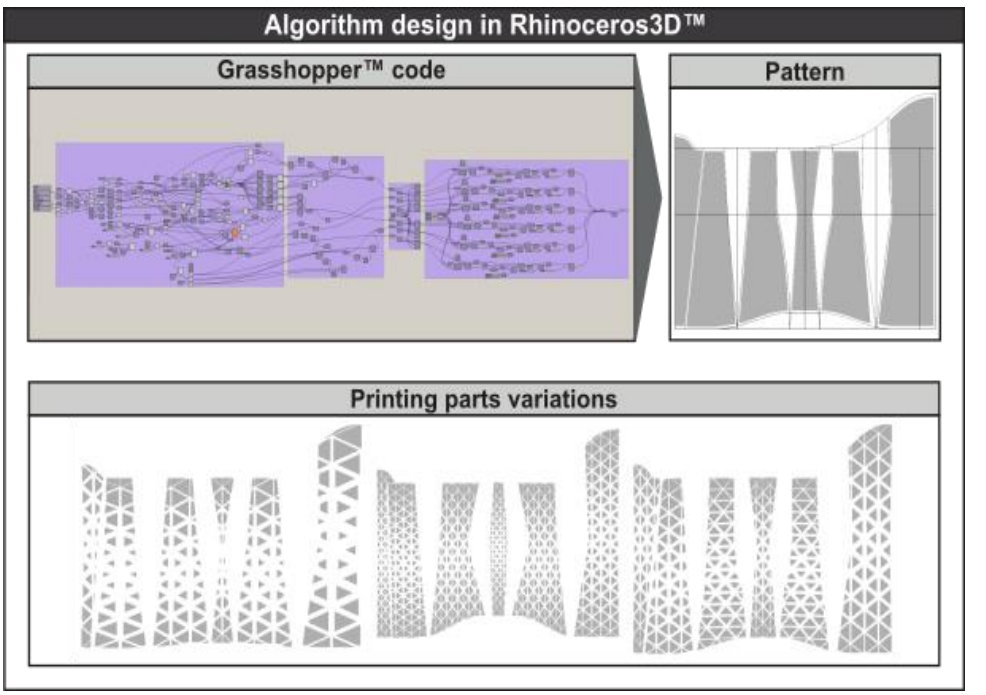

Figure 2: Parametric design in Grasshopper™

3.2. Material Selection

Table 1 depicts the material selection followed with the appropriate description for each case.

Table 1: Table of Materials Used

Material	Description/Function
Wool fabric	Black base layer; structural and aesthetic surface
Tulle fabric	Printed substrate: lightweight mesh stitched to wool
PLA (white)	3D-printed structural elements for posture reinforcement
White and black thread	Hand-sewn to attach layers and finish edges
Satin bias tape	Edge finishing and decorative contouring
Cord	Used for lacing and tightening the corset
Rivets/eyelets	Reinforced holes for corset lacing

3.3. Digital Fabrication: 3D Printing on Textiles

The 3D Creatbot™ D600 Pro based on Fused Filament Fabrication technology was used for the specimens' fabrication, while the 3D printing process was conducted using the settings presented in Table 2.

Table 2: Table of 3D printing parameters

Parameter	Value
Nozzle Temperature:	225 [°C]
Bed Temperature:	50 [°C]
Infill:	100%
Filament Diameter:	1.75 [mm]
Nozzle Diameter:	0.6 [mm]
Printing Speed:	40 [mm/sec]
Perimeter Speed:	50%
Cooling Fan:	100%

The white tulle textile was secured to the build plate using hot-melt adhesive (hot glue) (Fig. 3). This textile was chosen because of its perforation, which aided in the adhesion of the printed parts to the fabric.

Figure 3: Printer setup and fabric mounting detail

4. RESULTS AND DISCUSSION

The prototype (Fig. 4) maintained flexibility in non-printed regions and showed adequate bonding strength without the use of chemical pre-treatment. The garment enhanced posture awareness, with limited restrictions. Some delamination occurred at high-flex points, indicating the need for structural optimization. The parametric design workflow enabled quick customization, highlighting potential for on-demand personalization.
However, going from PLA on tulle to a fully made corset was a lengthy process that could potentially become more streamlined and efficient.

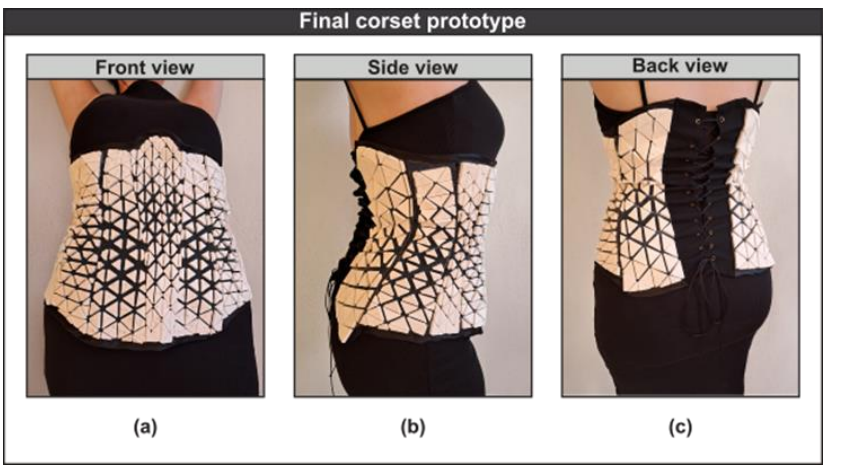

Figure 4: Final corset prototype worn by test subject

5. CONCLUSION

This study demonstrates the potential of 3D printing on textiles for wearable posture support. Through a computational and material-driven process, a corset was developed that is structurally supportive, comfortable, and visually engaging. The study endorses the viability of hybrid textile-fabrication workflows for bespoke, health-aware fashion.
Future directions include the exploration of flexible filaments, bio-based composites, and quantitative motion capture to better evaluate long-term posture impact.

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EVALUATING THE CLOTHING COMFORT OF POLYESTER FABRICS ENGINEERED WITH CORE-SPUN ELASTANE YARNS

Original scientific paper
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ABSTRACT: *In this study, the performance, comfort, and stretch properties of polyester knitted fabrics containing core-spun elastane yarns with varying linear densities were investigated. Ne 16 core-spun yarns were produced using elastane filaments of 20, 40, 70, and 140 denier as the core material, and polyester staple fibers (38 mm, 1.2 dtex) as the sheath material. Single jersey fabrics were knitted by these yarns. The targeted properties of these fabrics were compared with, the sample in which elastane was incorporated during the knitting process rather than via core-spun yarn production. As a result, core-spun fabrics produced with 20 dtex elastane were found to exhibit better performance regarding thermal comfort in sportswear. Moreover, a regression equation was derived to estimate the elastane ratio in knitted fabrics based on yarn production parameters, offering practical utility for industrial applications.*

Keywords: *core-spun yarn, elastane, knitted fabric, performance properties, regression model.*

PROCENA UDOBNOSTI ODEĆE OD POLIESTERSKIH TKANINA IZRAĐENIH SA ELASTANSKIM JEZGRO-PREĐENIM PREDIVIMA

APSTRAKT: *U ovoj studiji ispitivane su performanse, udobnost i rastegljive osobine poliesterskih pletenih tkanina koje sadrže jezgro-pređena prediva sa elastanom različitih linearnih gustina. Jezgro-pređena prediva Ne 16 proizvedena su korišćenjem elastanskih filamenata od 20, 40, 70 i 140 dtex kao jezgra, i poliesterskih rezanih vlakana (38 mm, 1.2 dtex) kao omotača. Od ovih prediva pletene su jednolične (single jersey) tkanine. Ciljane osobine ovih tkanina upoređene su sa uzorkom u kojem je elastan dodat tokom procesa pletenja, a ne putem proizvodnje jezgro-pređenih prediva. Kao rezultat, utvrđeno je da tkanine sa jezgrom od 20 dtex elastana pokazuju bolje performanse u pogledu termalne udobnosti za sportsku odeću. Pored toga, izvedena je regresiona jednačina za procenu procenta elastana u pletenim tkaninama na osnovu parametara proizvodnje prediva, što nudi praktičnu vrednost za industrijsku primenu.*

Ključne reči: *jezgro-pređeno predivo, elastan, pletena tkanina, performansne osobine, regresioni model.*

1. INTRODUCTION

The increasing demand for high-performance textile products has driven extensive research into the functional properties of knitted fabrics. In recent years, the use of elastane in knitted fabrics has become increasingly widespread, driven by the growing need for garments that offer both comfort and functionality. Elastane is widely appreciated for its elastic properties, which allow fabrics to recover their shape after stretching and provide a better fit to the human body. Depending on how it is incorporated into the yarn—either as a core-spun component or through bare feeding—elastane can significantly influence the fabric's physical behavior.

Key fabric characteristics such as bursting strength, thickness, air permeability, and thermal properties are closely linked to the structural configuration of the yarn, particularly the core-to-sheath ratio and the denier of the elastane used. Although previous studies have examined the general effects of elastane on fabric properties, the combined influence of yarn structure and elastane thickness on both mechanical performance and thermal regulation remains less explored. Several studies have examined the impact of elastane on the structural and comfort-related properties of knitted fabrics [1-5]. Marmaralı et al., Hes et al. and Özdil found that increasing elastane content in knitted and denim fabrics enhances thermal resistance and elastic recovery, while reducing thermal conductivity, water vapour permeability, and dimensional deformation. Herath et al. [6] and Sadek et al. [7] reported that elastane improves dimensional stability and elongation, particularly in single jersey fabrics. Azim et al. [8] and Eryuruk & Kalaoğlu [9] highlighted its influence on air permeability, fabric weight, bursting strength, and spirality. Ertekin et al. [10] observed that higher elastane ratios increase thickness, strength, and thermal conductivity but cause limit breathability. Uyanık [11] and Cingü [12] further emphasized the role of elastane type, denier, and feeding method on thermal comfort, elongation behavior, and surface properties.

This study aims to investigate the effect of elastane configuration on the overall performance of knitted fabrics. For this aim the fabric properties such as thermal resistance, water vapour permeability, air permeability, fabric weight, and elastane content were determined. The obtained results will provide significant data for material selection and design studies in application fields where comfort, breathability and durability are important.

2. EXPERIMENTAL STUDY

In this study, the performance, comfort, and elasticity properties of polyester fabrics containing elastane in different lineer densities were analyzed and compared with the method of feeding elastane into the fabric during knitting production. Additionally, the aim

was to develop an equation that identifies the relationship between the the relationship between the core/sheath ratio of the yarn and elastane ratio by weight (%), which could be practically applied in the industry.

As the core material; elastane filaments of different lineer densities (22, 44, 78, and 156 dtex) were used, while staple PES fibers were employed as the sheath material. The PES fibers used in the experiments had a fineness of 1.2 dtex and a staple length of 38 mm and were used in the form of slivers in 295 tex.

According to experimental plan (Table 1), 5 different types of core-spun yarns with a lineer density of 37 tex (final yarn count) were produced using the core-spinning technique on Pinter Merlin ring spinning machine. Draw ratios were 3.5 for feeding elastane filament. Core-spun polyester yarns containing elastane were used to produce single jersey knitted fabrics. To observe the effects of elastane in knitted fabrics, PES yarns without elastane were also produced.

Table 1: Experimental plan for yarn production.

	2	5	8	11	
Elastane (denier)	20	40	70	140	-
Elastane (dtex)	22	44	78	156	-
Sheath (tex)	36	35	34	32	37
Sliver draft ratio	12.1	12.5	12.5	13.7	11.9

To observe the effects of variable parameters, all spinning parameters were kept constant (Yarn twist was 600 T/m, spindle speed to 10,000 rpm, and traveler number to 4). The yarns produced on the ring spinning machine were used to manufacture single jersey tubular fabrics using the Mesdan Labknitter machine with 220 needles under constant machine settings. Additionally, fabrics were produced by incorporating naked elastane (40 denier) commonly used in knitted fabrics, into elastane-free PES yarns for comparison with core-spun yarns. Furhermore, to observe the effect of elastane, a fabric was also produced under the same conditions without any elastane. Production machines are given in Fig 1.

(a) (b)

Figure 1: (a) Pinter Merlin ring spinning machine (b) Mesdan Labknitter

The yarn and fabric tests were done after conditioned for 24 hours at standard atmospheric conditions. Yarn properties such as irregularity, tensile strength, and elongation at break

were evaluated, while fabric tests included thickness, weight, air permeability, water vapor permeability, thermal resistance, bursting strength, pilling, stretch (permanent elongation and elasticity), and pressure tests. Additionally, the elastane content in the fabric structure was measured using chemical methods (DMF dissolution method).

3. RESULTS AND DISCUSSION

According to test results in Table 2, an increase in elastane thickness resulted in a decrease in tensile strength while an increase in yarn hairiness and breaking elongation. The decrease in tensile strength with the increase of elastane thickness is thought to be due to the reduced amount of PES fibers in the sheath part of the core-spun yarn. On the other hand, no significant difference was found among the yarn unveness values.

Table 2: Yarn uneveness, hairiness, tenacity and breaking elongation test results.

Elastan no	Yarn unevenness	Yarn hairiness		Yarn tenacity		Breaking	
	CVm %	H	sh	μ	CV %	μ	CV %
20 den	8,39	4,92	0,97	39,99	5,18	15,37	3,22
40 den	8,09	6,38	1,13	37,86	4,85	15,5	3,15
70 den	8,67	8,01	1,58	36,01	6,07	16,08	5,21
140 den	8,67	8,01	1,58	30,51	4,38	17,53	3,45

The fabric labeled with the code "NoEL" represents the elastane-free control sample, while the fabric labeled with the code "NakedEL" refers to the sample produced by incorporating naked elastane into the structure during the knitting process.

Table 3: Fabric weight, thickness, elasticity and pilling test results.

	Soft core-spun yarns				**No-elastane**	**Naked elastane**
Elastane lineer density (denier)	**20**	**40**	**70**	**140**	**-**	**-**
Fabric weight (g/m²)	234.5	253.4	288	367.7	210.1	228.9
Fabric thickness (mm)	1.05	1.26	1.28	1.43	1.01	1.00
Fabric elasticity S (%)	60.7	71.47	79.03	70.22	58.50	63.70
Pilling degree	3/4	2/3	3/4	3/4	4	2/3

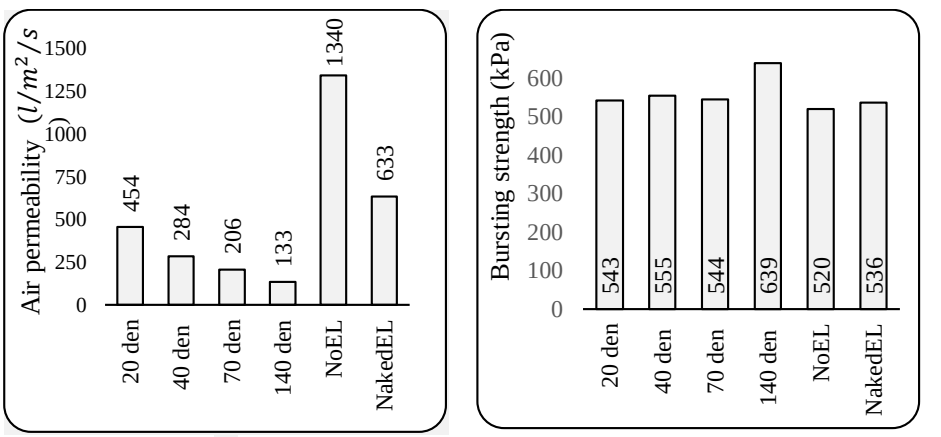
In Table 3, S (%) stands for strain percentage, representing the relative elongation of the specimen. Fabrics elongation and elasticity values are the mean values obtained from the tests performed in wale and course direction. As expected from the stretchability tests of knitted fabrics, the elasticity values in the course wise direction were found to be higher than along wales. On the other hand, no significant effect of the elastane denier was

observed. Core-spun yarns outperform naked elastane and no-elastane fabrics in elasticity. 70 denier core-spun elastane offers the highest elasticity and controlled deformation.

In general, an increase in elastane thickness resulted in a higher fabric weight in knitted fabrics (According to ISO 12127). As the thickness of elastane increases, the thickness of the knitted fabric also increases (According to ASTM D 1777). When the same elastane count is used, a difference in fabric thickness is observed between the knitted fabric containing core-spun elastane yarn and the fabric produced with naked elastane feeding. This difference indicates that the fabric containing core-spun yarn is thicker.

The pilling test results of the fabrics generally ranged between grades 3 and 4, regardless of the elastane thickness (According to ISO 12945-1).

The air permeability results of the knitted fabrics, as shown in the figure, demonstrate a clear decreasing trend with increasing elastane thickness (According to ISO 9237). Fabrics containing 140 denier elastane exhibited the lowest air permeability value at 133 l/m²/s, while those with 20 den showed a higher permeability at 454 l/m²/s. This trend suggests that thicker elastane content leads to a denser fabric structure, thereby restricting airflow more significantly. The fabric without elastane (NoEL) displayed the highest air permeability (1340 l/m²/s), confirming that the absence of elastane contributes to a looser fabric structure with higher porosity. The naked elastane containing sample (NakedEL) showed a permeability of 633 l/m²/s, which is significantly higher than any of the core-spun elastane-fed fabrics but still lower than the NoEL fabric. This result indicates that core-spun elastane integration not only affects elasticity but also leads to notable compactness, which significantly reduces air permeability compared to naked elastane feeding.



(a) (b)

Figure 2: (a)Air permeability (b) Bursting strength values of the fabrics.

The bursting strength of knitted fabrics varies slightly depending on the elastane thickness and feeding method. The highest bursting strength was recorded for the fabric produced with 140 denier elastane, reaching 639 kPa, indicating a clear reinforcement effect at higher denier levels (According to ISO 13938-2). Other elastane-containing samples (20, 40, and 70 den) exhibited relatively close values, ranging between 543 and 555 kPa, suggesting that changes in denier within this range have a limited impact on bursting strength. Fabrics

produced without elastane (NoEL) and those with naked elastane (NakedEL) showed lower bursting strengths, measured at 520 kPa and 536 kPa, respectively. This indicates that core-spun elastane, particularly with higher deniers, provides a compact structure and high resistance more effectively than naked elastane feeding.

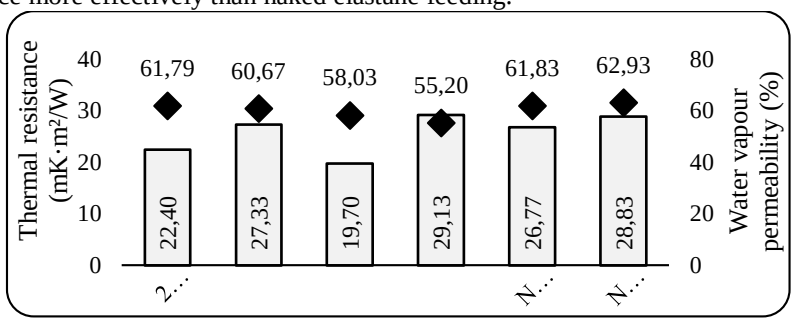


Figure 3: Thermal resistance and water vapour permeability (%) values of the fabrics.

This figure illustrates the thermal resistance (expressed in mK m²/W) and water vapour permeability (%) of various knitted fabric samples containing different elastane thicknesses and feeding methods (According to ISO 11092). The fabric produced with 140 denier elastane exhibited the highest thermal resistance at 29.13 mK m²/W, indicating improved insulation properties. The general trend suggests that as elastane thickness increases, thermal resistance also increases due to a denser fabric structure.

Water vapor permeability values range from 55.20% to 62.93%. NakedEL sample, similar to the fabric knitted by 40 den core-spun elastane, exhibits the highest vapor permeability while also providing higher thermal resistance, meaning a fabric that has adequate insulation but also has sufficient breathability.

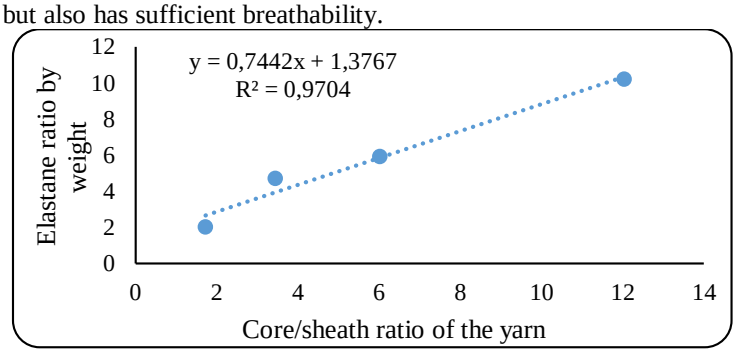


Figure 4: The relationship between fabrics' elastane ratio by weight and core/sheat ratio of the yarn.

In Figure 4, the scatter plot displays the relationship between the core/sheath ratio of the yarn and the elastane ratio by weight (%). The fitted linear regression model is represented by the equation:

$$y = 0.7442x + 1.3767, \quad (1)$$

with a coefficient of determination $R^2 = 0.9704$. A strong linear correlation is observed between the core/sheath ratio and elastane ratio by weight, as evidenced by the high R^2 value (0.9704), indicating that over 97% of the variation in elastane content can be explained by the core/sheath ratio. As the core proportion increases relative to the sheath, the elastane content in the yarn increases proportionally. This is expected, since elastane is generally located in the core region of the yarn. The regression line indicates that for each unit increase in the core/sheath ratio, the elastane content increases by approximately 0.74% by weight.

4. CONCLUSION

In this study, the effect of various elastane configurations on the performance characteristics of knitted fabrics was investigated in detail. Key focus areas included bursting strength, air permeability, thermal resistance, water vapor permeability, and elastane content in relation to yarn structure.

- The results revealed that increasing the elastane thickness, particularly in core-spun yarns, contributed significantly to the mechanical strength of the fabric. The sample containing 140 denier elastane exhibited the highest bursting strength, while fabrics produced without elastane or with naked elastane showed comparatively lower performance in this regard.
- A clear trend was also observed in terms of air permeability. As the elastane denier increased, fabrics became progressively less breathable, which is attributed to the denser structure formed by higher elastane content. Fabrics produced by naked elastane showed moderate permeability, between core-spun and elastane-free fabrics.
- The analysis of thermal comfort properties showed that samples with greater elastane thickness offered better thermal insulation. However, this also resulted in a reduction in water vapour permeability, suggesting a balance between insulation and breathability. Among all samples, the 40 denier core-spun or naked elastance feeding provided the most balanced thermal comfort characteristics.
- Furthermore, the relationship between core/sheath ratio and elastane ratio by weight was found to be strongly linear, as indicated by a high coefficient of determination ($R^2 = 0.9704$). This finding underscores the predictability of eelastane distribution in yarn based on structural parameters.

Ovrall, the study shows that core-spun yarns with thicker elastane content enhance strength and insulation, though they may limit breathability. These insights can guide the development of knitted fabrics tailored for specific functional requirements, depending on whether durability, insulation, or comfort is prioritized.

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PATCH FABRIC DESIGN FEATURING NATURAL OIL-FUNCTIONALIZED NANOFIBER COATING FOR DRY SKIN

Original scientific paper
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ABSTRACT: *Dry skin is a common dermatological condition that results from the disruption of the skin's moisture balance, often accompanied by symptoms such as itching, flaking, and sensitivity. This study aims to develop and evaluate the effectiveness of fabric patches functionalized with nanofibers containing natural oils, which can be easily attached to the inner surfaces of garments.*

Coconut, St. John's wort, and lavender oils are well-known for their beneficial effects in skincare. These oils were incorporated into thermoplastic polyurethane (TPU) nanofibers and coated onto fabric surfaces. The opposite side of the fabric patches was equipped with skin-friendly, pressure-sensitive adhesive bands, allowing the patches to adhere securely to the inner surfaces of various garments. This design enables users to place the patches over areas of dry skin as needed and replace them when necessary.

It is expected that nanofibers functionalized with these natural oils will have a positive impact on alleviating skin dryness. In this preliminary study, general information is provided about coconut, St. John's wort, and lavender oils, as well as nanofibers functionalized with natural oils and their potential applications. The fabrication of TPU nanofibers functionalized with coconut oil and their integration into fabric patch form are also presented. The functionalized nanofibers were characterized by scanning electron microscopy (SEM), water contact angle measurement, and oil release characteristic. As a result, the developed patches are proposed as functional medical textile materials with potential application in soothing dry skin.

Keywords: *Coconut oil, nanofibers, skin dryness, functional nanofiber patches.*

DIZAJN PATCH TKANINE SA NANOVLAKNASTIM PREMAZOM FUNKCIONALIZOVANIM PRIRODNIM ULJIMA ZA TRETMAN SUVE KOŽE

APSTRAKT: *Suva koža je uobičajeno dermatološko stanje koje nastaje usled narušene ravnoteže vlažnosti kože, a često je praćeno simptomima kao što su svrab, perutanje i osetljivost. Ova studija ima za cilj razvoj i evaluaciju efikasnosti flaster tkanina funkcionalizovanih nanovlaknima sa prirodnim uljima, koje se mogu lako pričvrstiti za unutrašnje površine odeće.*

Kokosovo ulje, kantarionovo ulje i ulje lavande poznata su po svojim blagotvornim efektima u nezi kože. Ova prirodna ulja su inkorporirana u termoplastični poliuretan (TPU) nanovlakna i naneta na površinu tkanine. Suprotna strana tkanine je opremljena koži prijemčivim, na pritisak osetljivim lepljivim trakama, koje omogućavaju sigurno prijanjanje za unutrašnje površine različitih odevnih predmeta. Ovakav dizajn omogućava korisnicima da flastere postave na područja kože sa izraženom suvoćom i po potrebi ih zamene.

Očekuje se da nanovlakna funkcionalizovana ovim prirodnim uljima imaju pozitivan efekat u ublažavanju simptoma suve kože. U ovoj preliminarnoj studiji data je opšta informacija o kokosovom, kantarionovom i ulju lavande, kao i o nanovlaknima funkcionalizovanim prirodnim uljima i njihovim potencijalnim primenama. Prikazana je izrada TPU nanovlakana funkcionalizovanih kokosovim uljem i njihova integracija u oblik tkanih flastera. Funkcionalizovana nanovlakna su karakterisana pomoću skaning elektronske mikroskopije (SEM), merenja kontaktnog ugla vode i profila oslobađanja ulja. Kao rezultat, razvijeni flasteri se predlažu kao funkcionalni medicinski tekstilni materijali sa potencijalnom primenom u ublažavanju suve kože.

Ključne reči: *Kokosovo ulje, nanovlakna, suva koža, funkcionalni nanovlaknasti flasteri.*

1. INTRODUCTION

The term 'xerosis' or 'dry skin' is commonly used by doctors, patients, and the cosmetic industry to describe skin that feels rough, flaky, cracked, and lacking moisture. It is often linked to atopic skin conditions and mild forms of ichthyosis vulgaris [1]. Dry skin is a common dermatological condition that results from the disruption of the skin’s moisture balance, often accompanied by symptoms such as itching, flaking, and sensitivity. Dry skin often results from a mix of factors, including genetic background, environmental conditions, age, and ethnic differences [2]. Managing dry skin typically involves the use of emollients. An ideal emollient is suggested to include five essential components: humectants, non-physiological lipids (such as mineral or vegetable oils), physiological lipids (like ceramides and free fatty acids), soothing or anti-itch agents, and ingredients that promote epidermal differentiation [2].

Natural plant-based oils (fixed and essential oils) are widely used around the world as topical treatments due to their affordability and easy accessibility. Many of these oils contain active compounds with antimicrobial, antioxidant, anti-inflammatory, and antipruritic effects, making them appealing as alternative or complementary options in the management of xerotic and inflammatory skin conditions linked to barrier dysfunction [3]. There are several techniques for obtaining oils, including cold pressing for unrefined oils, heat or chemical distillation for essential oils, and the use of synthetic additives to create fragranced oils. Among these, the extraction and refinement method significantly influence the oil's suitability for skin care. Fixed oils—also known as carrier oils—which are non-volatile triglyceride-based compounds derived from plant or animal sources. Cold pressing is generally favored, as it avoids heat and chemicals, helping to retain beneficial lipids while minimizing the formation of potentially irritating byproducts [3-5].

In contrast, essential oils are volatile natural compounds extracted from various parts of plants, such as leaves, flowers, seeds, roots, or bark [5] generally through steam distillation or cold pressing. While fixed oils are composed of triglycerides, essential oils mainly consist of terpenoids, phenolics, polyacetylenes, and phthalates. Due to their low boiling points and tendency to evaporate at room temperature, they are termed "volatile oils." Microencapsulation of essential oils has enabled their application in pharmaceutical and biomedical fields. The incorporation of essential oils into polymeric nano- and microfibers offers novel approaches in biomedical applications such as wound dressings, tissue engineering scaffolds, and controlled/targeted drug delivery. Like fixed oils, essential oils are hydrophobic and soluble in organic solvents, although their polarity can vary [5].

The ability to be functionalized is one of the key advantages of nanofiber-based materials, enabling their application across a broad range of fields. A variety of active agents—such as antibacterial, moisturizing, or therapeutic compounds that support wound healing—can be incorporated into nanofibers. Natural oils, including coconut oil, St. John's wort oil, and lavender oil, may also serve as active agents. Nanofibers loaded with these natural oils can be engineered into patch-like systems with an adhesive layer, allowing for easy application to the skin and providing relief from dryness.

One such example is coconut oil (Cocos Nucifera oil), a natural moisturizer effective in relieving dry skin. Its medium-chain fatty acids, particularly lauric acid, help maintain the skin's moisture balance and reduce transepidermal water loss (TEWL), keeping the skin hydrated. It also exhibits anti-inflammatory and antioxidant properties that soothe sensitive or irritated skin [6, 7]. Coconut oil typically appears as a white or light-yellow to orange semi-solid substance. It has a density of approximately 0.92 g/cm³ and is insoluble in water. Coconut oil is non-toxic and primarily consists of glycerides of myristic, palmitic, stearic, oleic, and linoleic acids [8]. Scientific studies indicate that coconut oil strengthens the skin barrier and is as effective as mineral oils in moisturization. Mohamadi et al. encapsulated coconut oil into blend nanofibers of PCL, a hydrophobic synthetic polymer with high mechanical properties, and Gel, a natural, biocompatible, biodegradable, and hydrophile polymer as a potential wound dressing candidate [9]. They also investigated in vivo wound healing property of coconut oil loaded nanofiber/hydrogel hybrid scaffold in anothor study [10]. Jaganathan et al. produced coconut oil loaded polyurethane nanofibers for vascular graft applications [11].

St. John’s Wort oil (Hypericum perforatum oil) is a natural essential oil with strong healing and moisturizing effects on the skin. Components such as hypericin, flavonoids, and essential fatty acids support the skin barrier, reduce dryness, and maintain skin hydration. Its anti-inflammatory and cell-regenerating properties help soothe irritated and stretched skin [12, 13]. Research has shown that St. John’s Wort oil promotes epithelial regeneration and accelerates wound healing [14], making it a promising natural option for moisturizing and improving skin elasticity. Sivri and Sakarya used St. John’s Wort oil and some other extracts with polyethylene oxide (PEO) and polyvinyl alcohol (PVA) polymers, produced nanofiber membranes by electrospinning and investigated their use as wound dressing materials [15]. Arik et al. reported the production of St. John’s Wort oil, lavender oil, and virgin olive oil loaded thermoplastic polyurethane [16].

Lavender oil (Lavandula angustifolia) is also widely used natural essantial oil in skincare due to its antiseptic, anti-inflammatory, and soothing effects [17]. In addition to being effective against dryness, it can relieve irritation and support the healing process. Lavender oil enhances skin hydration and strengthens the skin barrier, providing relief particularly for dry and stretched skin. It may also support skin elasticity and prevent stretch marks by improving blood circulation. Its antibacterial and antifungal activities also contribute to a faster healing process, making it a natural and effective remedy for skin dryness and related discomfort. Several researchers [18-20] were also used lavender oil in electrospinning for various biomedical purposes.

Nanofibers are commonly produced by the electrospinning method. In this technique, a high-voltage power supply, a syringe (nozzle) containing the polymer solution, and a collector area are used. The potential difference between the nozzle and the collector stretches the polymer solution, forming a fine jet that travels toward the collector. During this process, the solvent evaporates, and extremely fine nanofibers accumulate on the collector [21]. Surfaces of electrospun fibers possess a high surface area compared to conventional film-forming methods and exhibit high porosity and small pore sizes, closely resembling the native extracellular matrix (ECM) [22].

Incorporating fixed oils like coconut oil into nanofibers presents a promising alternative approach for skin therapy. Nanofibers can act as an effective carrier matrix for these oils, providing a novel and efficient delivery system for topical application. Besides, the controlled release of essential oils from nanofibers may help mitigate their potential cytotoxic effects on human cells. Furthermore, essential oils gain increased stability in these nanofiber systems, extending shelf life and supporting commercialization. Studies have focused on overcoming the limitations of essential oils such as volatility, low stability, and sensitivity to environmental factors, while also evaluating their biological effects [23]. Findings show that integrating essential oils into engineered biomaterials enhances antibacterial activity, biocompatibility, and wound healing. The combination of biomaterials with fixed and essential oils presents a promising strategy for creating advanced hybrid biomedical systems capable of delivering natural therapeutic agents

This study aims to develop and evaluate the effectiveness of fabric patches functionalized with nanofibers containing natural oils, which can be easily attached to the inner surfaces of garments by pressure-sensitive adhesives (PSAs). PSAs have become integral

components in medical and drug delivery systems due to their unique properties that allow for gentle yet effective adhesion to the skin and other biological surfaces [24, 25]. These adhesives form a bond when light pressure is applied, without requiring solvents, heat, or water for activation, making them ideal for sensitive and delicate applications [26]. In medical devices, PSAs are widely used in wound dressings, transdermal patches [27], and wearable sensors [28], where secure attachment and patient comfort are paramount. Their ability to conform to irregular skin surfaces ensures sustained contact, which is critical for effective drug absorption and monitoring. Moreover, the biocompatibility and hypoallergenic nature of medical-grade PSAs reduce the risk of skin irritation and allergic reactions, supporting long-term use. Advances in PSA formulations have also enabled controlled drug release profiles when integrated into transdermal systems, enhancing therapeutic outcomes [28, 29]. The selection of an appropriate PSA depends on factors such as adhesion strength, peel resistance, moisture permeability, and compatibility with both the drug and the skin.

In this preliminary study, the fabrication of TPU nanofibers functionalized with coconut oil and their integration into a fabric patch form are presented. The functionalized nanofibers were characterized using scanning electron microscopy (SEM) and water contact angle measurements. Additionally, a simple gravimetric oil release test was conducted to quantify the amount of oil transferred to a piece of paper. As a result, the developed interchangeable patches are proposed as functional medical textile materials with potential applications for relieving dry skin. These patches are designed for limited-period use and should be replaced with a new one after a certain application time.

2. MATERIALS AND METHODS

2.1. Materials

For the electrospinning process, TPU material, Pellethane® 2103-80AE, composed of 4,4'-methylenebis (phenyl isocyanate), polytetramethylene oxide, and 1,4-butanediol, was utilized. This TPU was supplied by Velox on behalf of Lubrizol Advanced Materials. The solvent N,N-dimethylformamide (DMF) was sourced from Sigma-Aldrich. Cold-pressed Life In brand coconut oil, with a melting point of 24 °C, was locally sourced. Henkel AQUENCE, water-based PSA was used to form an adhesive layer. A non-stick paper was used to cover this adhesive layer. Whatman filter papers were used to analyze the gravimetric oil release behavior.

2.2. Method

A polymer solution with a concentration of 9 and 10% TPU was prepared based on insights from earlier research [Oğlakcıoğlu et al. 2021]. TPU granules were dissolved in DMF at ambient temperature. Coconut oil was added at amounts corresponding to 100% and 200% of the polymer weight, and mixing was continued until a homogeneous mixture was obtained. The samples were coded as 100CO-10TPU, 100CO-9TPU, and 200CO-9TPU. In the sample codes, 'CO' refers to the amount of coconut oil added relative to the polymer weight, and 'TPU' indicates the polymer content (g) in the solution. For example, 100CO-10TPU represents a sample containing coconut oil at 100% of the polymer weight and 10 g of TPU.

Electrospinning was performed using a system that included a 10 mL syringe equipped with a 2.5 cm long, 22-gauge flat-tip needle, a grounded electrode, and a high-voltage power supply (Pulselectronic, 20 kV DC output). The process was carried out under an applied voltage of 13 kV, with the distance between the needle tip and the collector set at 18 cm, and a flow rate of 2 mL/h. As the collector, a rotating grounded metal drum wrapped in jersey fabric pre-treated with Henkel's Aquence was used for fiber deposition.
The bottom side of the fabric was also coated with Henkel's Aquence and covered with a non-stick protective release liner to preserve its adhesiveness until use.

2.3. Characterization

Morphology of the samples was characterized by scanning electron microscopy (SEM, Phenom Prox G6 instrument). Each sample was coated with thin film of gold using Emitech K550X ion sputtering device at 15 mA and $8x10^{-2}$ mbar vacuum for 2 minutes.
The wettability characteristic of the coconut oil loaded TPU nanofiber membrane was assessed by measuring the water contact angle (WCA) using a CAM 200 contact angle goniometer (KSV Instruments, Helsinki, Finland). The measurement wa carried out on the top surface of the electrospun membranes using distilled water at ambient conditions (25 °C, 40–50% relative humidity). A 2 µL water droplet was carefully dispensed from a height of 5 cm onto the membrane surface through a vibrating micro-syringe. After 15 seconds of stabilization, the droplet was observed for a duration of 2 minutes to ensure that no significant deformation or absorption took place.
To characterize the oil release behavior of the coconut oil-loaded TPU nanofibers, a gravimetric method was employed. A piece of Whatman filter paper was placed on top of the prepared nanofiber patch and incubated at 37 °C. At predetermined time intervals (1 h, 3 h, 5 h, 8 h, 24 h, 28h, 36h and 48h), the filter paper was weighed to determine the cumulative amount of oil transferred from the nanofibers.

3. RESULTS AND DISCUSSION

SEM images of 100CO-10TPU, 100CO-9TPU and 200CO-9TPU nanofibers at two different magnifications. The images clearly show a dense oil coverage on the nanofiber surfaces. While nanofiber formation was achieved for 100CO-10TPU, the fiber structure was almost lost in 200CO-9TPU. In the case of 100CO-9TPU, coconut oil was extensively distributed across the fiber surfaces and appeared to fill the inter-fiber gaps.

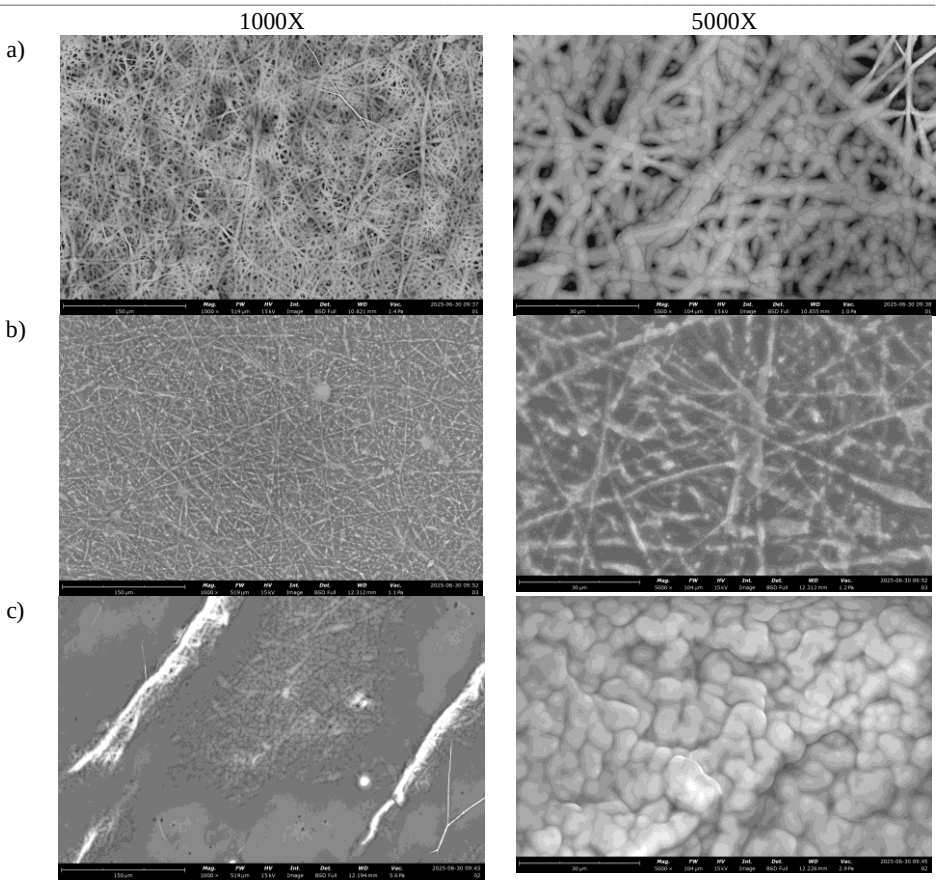

Figure 1: SEM images of 1000X and 5000X magnification of a) 100CO-10TPU, b)100CO-9TPU and c) 200CO-9TPU nanofibers

The water contact angle (WCA) between the water droplet and the sample was measured for 100CO-10TPU nanofibers, and the corresponding image (Figure 2) was captured after 15 seconds. The average WCA value, calculated from the right, middle, and left positions of the droplet, was determined to be 103°. Since the WCA of the sample exceeded 90°, it can be classified as hydrophobic.

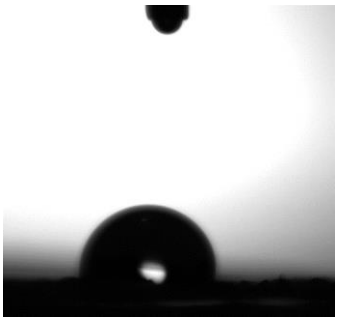

Figure 2: WCA image showing a contact angle of 103° for coconut oil-loaded TPU nanofibers

The release characteristics of coconut oil from the TPU nanofibers were shown in Figure 3. Coconut oil loaded nanofibers were placed with two paper pieces. The initial weight of the coconut oil-loaded nanofibers was recorded. At time intervals of 1 h, 3 h, 5 h, 8 h, 24 h, 28 h, 36 h, and 48 h, the samples were weighed, and the released amount of coconut oil was calculated relative to the initial coconut oil contentIt was observed that the release ratios of 100CO-9TPU and 100CO-10TPU samples were similar, both reaching approximately 40% of the total coconut oil content. When the initial loading of coconut oil was increased to 200% of the polymer weight, the total release ratio increased to approximately 60% of the initial loading. None of the samples released all of their oil content. However, it should be noted that the actual amount of coconut oil in the samples was not directly measured; instead, it was theoretically calculated based on the final weight of the samples. Representative images of the nanofibers and the oil stains on the white papers are presented in Figure 4. The oil stains released from the nanofibers were clearly visible in the presented images.

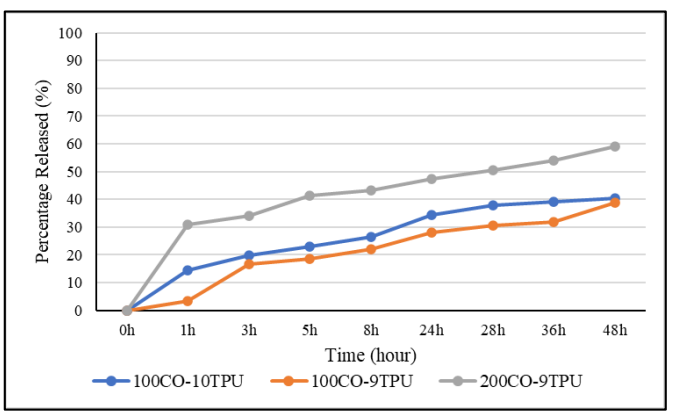

Figure 3: Percentage release of coconut oil-loaded 100CO-10TPU, 100CO-9TPU and 200CO-9TPU nanofibers

a) b)

Figure 4: Representative images of coconut oil loaded TPU nanofibers samples and oil-stained white papers

4. CONCLUSION

In this study, thermoplastic polyurethane (TPU) nanofibers functionalized with natural oils such as coconut oil were successfully fabricated and characterized. The morphological analysis revealed that the nanofiber structure was maintained at moderate oil loadings; however, excessive oil content led to a loss of fiber integrity. The oil release studies demonstrated that the amount of oil released increased with higher initial loading, yet complete release was not achieved, indicating a sustained release potential. Additionally, water contact angle measurements confirmed the hydrophobic nature of the functionalized nanofibers, which is beneficial for creating a protective barrier on the skin. The visual inspection of oil stains further supported the release behavior of the coconut oil from the nanofiber structures. Overall, the developed coconut oil-loaded nanofiber patches offer a promising approach as functional medical textile materials with potential applications in alleviating skin dryness. Future studies will focus on optimizing oil loading levels, assessing the long-term release profiles, and evaluating the biocompatibility and therapeutic efficacy of these patches

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THE SIGNIFICANCE OF PATTERN CONSTRUCTION IN JUMPSUITS: FOSTERING WOMEN'S CONFIDENCE AND EMANCIPATION

Original scientific paper
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ABSTRACT: *Women were historically forbidden to wear trousers, which are generally associated with men. According to the research, accepting a new fashion style required adherence to cultural norms, customs, and expectations regarding appropriate clothing. Given that it symbolizes the emancipation of women on many levels, the wearing of trousers by women emerged as a significant symbol and turning point in the history of gender and fashion. In today's world, the proportion of women who buy trousers has increased significantly compared to the proportion who buy skirts. Wearing trousers became a symbol of masculinity, strength, and fighting skills in a patriarchal society. The jumpsuit has had an interesting journey since its creation in the early 20th century as a practical item of clothing for paratroopers. It has established itself as an essential piece of clothing in women's fashion, from its origins as protective equipment, through its peak as a fashion statement in the 1970s, to the status of a multi-purpose universal piece. Inspired by this type of clothing that has great significance for women, two types of women's overalls were created in this work.*

Keywords: *jumpsuits, trousers, pattern construction, modeling.*

ZNAČAJ KONSTRUKCIJE KROJA U KOMBINEZONIMA: NEGOVANJE ŽENSKOG SAMOPOUZDANJA I EMANCIPACIJE

APSTRAKT: *Ženama je istorijski bilo zabranjeno da nose pantalone, koje se generalno povezuju sa muškarcima. Prema istraživanju, prihvatanje novog modnog stila zahtevalo je pridržavanje kulturnih normi, običaja i očekivanja u vezi sa odgovarajućom odećom. S obzirom na to da simbolizuje emancipaciju žena na mnogim nivoima, nošenje pantalona od strane žena pojavilo se kao značajan simbol i prekretnica u istoriji roda i mode. U današnjem svetu, udeo žena koje kupuju pantalone značajno se povećao u poređenju sa udelom žena koje kupuju suknje. Nošenje pantalona postalo je simbol muškosti, snage i borilačkih veština u patrijarhalnom društvu. Kombinezon je imao zanimljivo putovanje od svog nastanka početkom 20. veka kao praktičan odevni predmet za padobrance. Uspostavio*

se kao neophodan komad odeće u ženskoj modi, od svojih početaka kao zaštitne opreme, preko vrhunca kao modne izjave 1970-ih, do statusa višenamenskog univerzalnog komada. Inspirisani ovom vrstom odeće koja ima veliki značaj za žene, u ovom radu su kreirana dva tipa ženskih kombinezona.

Ključne reči: *kombinezoni, pantalone, izrada kroja, modelovanje.*

1. INTRODUCTION

Growing consumer demands and technological advancements have had an impact on the apparel industry's development. Having expert pattern-making abilities to satisfy customers is one of the requirements for being competitive in the apparel sector. As a result, a variety of pattern-making techniques have been developed to specify the appropriate size and fit of clothing for varied body types and measurements [1]. A collection of 2D template parts for a simple 3D garment makes up the clothes pattern. The use of computer-aided design (CAD) for the creation of clothing and virtual prototyping has recently emerged as a clear trend in various industries and designers [2,3,4]. These days, virtual prototyping enables us to create accurately and fast as well as swiftly changing clothing. The outcome of a wide range of methods that have also seen significant development over the past ten years is virtual clothing simulation [5]. Clothing that fits well should have the right proportions, sit correctly on the body, and be loose enough to avoid compression, pulling, and fabric distortions. Even though each customer's fit preference may be unique and subjective, clothing makers should consider the target market's body size and type when going through the manufacturing process.

Gender is visually expressed through clothing, which varies greatly from culture to culture. Playing complimentary roles is only one aspect of gender-specific attire; power dynamics are intricately linked. Although it might not necessarily change the current power dynamics, Western women's adoption of pants, for example, represents a substantial reinterpretation of femininity [6]. The "right to pants" for women is very new, even though women's trousers are now generally accepted. In summary, trousers were considered a man's garment since the 14th century, and in certain regions, they were even illegal for women to wear. Over time, trousers became a symbol of manhood, strength, and battle power in a patriarchal culture. So, the women's rights movement and the women's trousers movement have been intimately related since the middle of the 19th century. As a sign of women's independence and a new, active position in society, trousers were promoted [7]. However, the general female population responded to this new fashion trend with considerable hesitancy. When women were able to participate in sports, paid employment, and other male-dominated fields of society, they began wearing trousers [8,9]. When trousers first appeared in Western women's fashion in the 1920s and 1930s, they were hailed as a symbol of women's liberation in the years following World War I, since it was deemed vulgar for women to wear fabric between their legs until the 20th century [10]. Consequently, "pants" have often been an undergarment type throughout evolution [11]. They are defined as "an outer garment covering the body from the waist to the ankles, with independent region for each leg," with the front and back crotch lines being sewn through [12,13]. Compared to

skirts, trouser pattern generation requires more body dimension data, movement appropriateness is more important, and trouser patterns are more likely to display significant body form [14].

History and culture are intertwined with the fashion industry. Some pieces make a lasting impression on the fashion industry, even though trends change over time. The jumpsuit is one design trend that evolved from its practical beginnings to become a cherished and timeless style icon. The top and bottom of this garment are combined to create a single, flowing piece that exudes sophistication and style. It is the pinnacle of adaptability, providing a smooth fusion of style and utility. It is a popular runway sighting and a hallmark of high fashion. To fit the spirit of the season, designers are always reinterpreting this timeless classic by combining different fabrics and cuts [15]. The modern jumpsuit was created by Italian painter Ernesto Michahelles (1919), a member of the Futurist movement. Because of its "T" form, it was referred to as the "Tuta" in Italian back then, and skydivers and parachutists wore them. By designing "lounging pyjamas" that woman wore during the warmer months while vacationing on the French Riviera, Coco Chanel elevated the jumpsuit to a new level in the 1920s. In terms of society, she represents the new free woman who appeared at the turn of the 20th century, bringing with her a new form of femininity based on financial autonomy, freedom of movement, and an easy-going, natural style of dressing. She knew how the modern woman would dress and, she liberated women from the weight of superficiality that had previously limited their motions and, in the process, created a new ideal of femininity. For women who, like Chanel, yearned for their own independence, this new ideal evolved into a new identity [16]. The Italian designer Elsa Schiaparelli, who is frequently mentioned as Coco Chanel's competitor, produced silk jumpsuits in the next year (1930), giving the fashion a more refined and feminine edge. In the 1950s-1960s, the jumpsuit was revived with the update of wide pants known as palazzos and flares. Later, in the 1970s they peaked in the disco era. Pop stars like Cher and Abba adopted it as their style [17]. Karl Lagerfeld revitalized the Parisian fashion house Chanel in the 1980s by reimagining historic Chanel pieces in a chic-sexy postmodern pastiche. Lagerfeld created his first Prêt-à-Porter line in 1984, which included the first Chanel Jeans. Chanel gave young ladies a contemporary, out-of-the-ordinary pants look that reflected the current zeitgeist and fight for gender equality [11]. In the decades that followed, Yves Saint Laurent, André Courrèges, and Emilio Pucci brought their dramatic interpretations to fashionable European society. At the same time, Hollywood celebrities contributed to the glamorization of figure-elongating, cinched-waisted styles on the big screen [18]. During the 1980s and 1990s, key trouser fashion trends were characterized by unique silhouettes, fabric selections, and cultural influences that captured the essence of each decade. A variety of jumpsuit designs were identified, including tight, frequently neon or animal-print denim jumpsuits worn with matching T-shirts or sweaters; loose, baggy styles with huge pockets inspired by hip-hop and street fashion culture; and frequently narrower and cinched around the ankle. Pop music and young subcultures were the driving forces behind a bold, inventive, and vibrant fashion culture that was represented in all these trends [19,20].

One of the largest issues facing the apparel business is how to put together and fit clothing, and pattern development is crucial to the production of clothing [21]. Thus, the following

studies demonstrate the significance of clothing construction and its relationship to historical landmarks and fashion innovations [22-25]. Women are more likely than men to wear trousers today, and there is a growing need for pants that meet physical, aesthetic, and mobility-related goals in addition to functional ones. Jumpsuits provide a multitude of styling alternatives for any occasion, whether they are formal, informal, or extravagant [26]. Therefore, because jumpsuits blend practical design, psychological impact, cultural significance, and expressive potential into a garment that empowers the wearer both psychologically and visually, academic fashion studies see them as symbols of confidence. Guided by this reality, this paper aims to construct and model two types of women's overalls.

2. EXPERIMENTAL PART

In accordance with the above-presented topic, in this study two types of women's trousers models inspired by the jumpsuit fashion were created. Figure 1 shows the technical sketches and drawings of both models.

Model 1 description: This model has a side, slanted zipper, wide straight legs, two straps and two pockets with a decorative flap in the knee area. They are made of three different materials and have 3 front parts and 3 back parts. Figure 1 shows a sketch and technical drawing of both models.

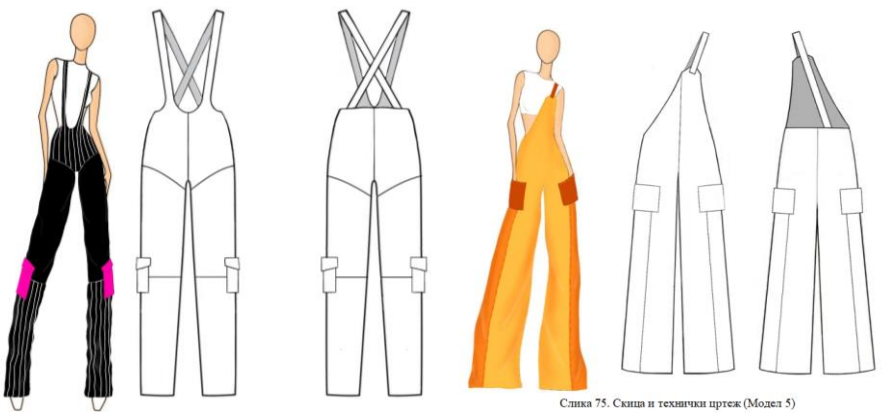

Figure 1: Technical sketch and drawing of Model 1 and Model 2

Model 2 description: It has wide legs and two pockets. The upper part has one strap. On these jumpsuits, the darts are taken in the width.

3. RESULTS AND DISCUSSION

The basic pattern design is created using body measurements and features a reasonable amount of mobility [27, 28]. So, the initial step in garment production is the creation of the cut patterns. Therefore, for both models, we use the basic construction of a woman's pants [29]. The second step is modeling the basic pattern construction.

For Model 1, the following modifications have been implemented:
- Widen the leg in the knee area and the length by 2cm;
- The dart is removed laterally, and model a strap 45 cm high and 3.5 cm wide at the top;
- The division of the front part into 3 parts. The first part is 25 cm from the waistline, from the side of the hips, and 3cm from the seat. The division of the second and third parts at the knee line. The modeling of the front part is shown in Figure 2.

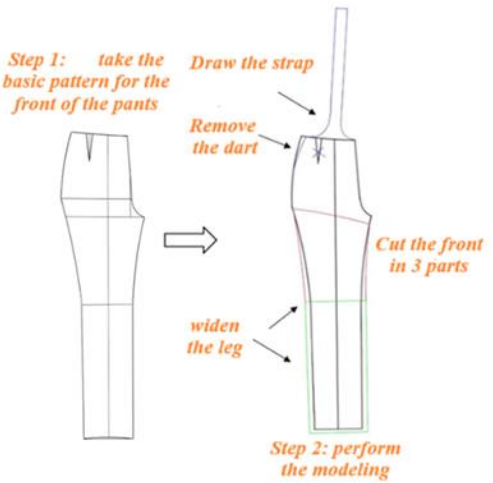

Figure 2: Model 1- Front modeling

The back part of Model 1 starts by removing the seam laterally and expanding the leg and dividing it into 3 parts, just like the front (Figure 3).

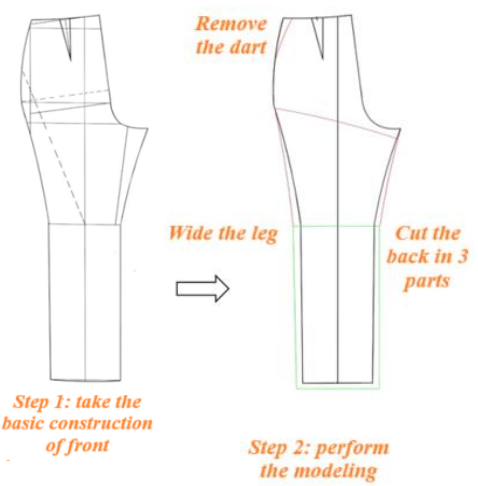

Figure 3: Model 1- Back modeling

The construction of the pockets and straps is presented in Figure 4. A pocket is being constructed with dimensions 20 x 15 cm, and the pocket flap with 17 x 3 cm and the top length of 5 cm. The strap is being constructed with dimensions 46 x 3.5 cm.

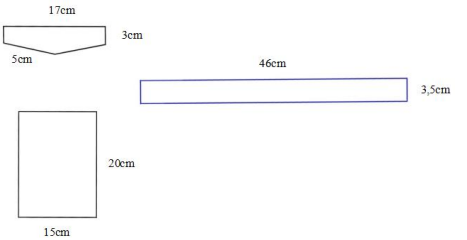

Figure 4: Modeling of strap, pocket, and pocket flap

The modeling of the front part of Model 2 is presented in Figure 5. Both front parts of this jumpsuit are modeled differently. The only difference is in the modeling of the upper part; the legs are the same. On the right front part, from the waist up, draw the upper part, which is 25 cm high, and let's take a dart in width. In the knee area, it expands the leg by 3.5 cm on one side and 3 cm on the other side. The length of the incision is extended by 3 cm. A separate piece is also marked on the leg, which is located 14 cm lower than the seat line and is 8 cm wide.

The back part (Figure 6) is modeled only in the leg area, and it is the same as the front part. In this part, we also take the seam in the width.

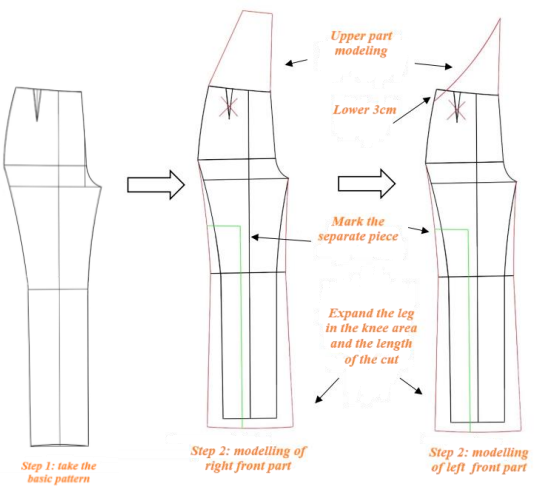

Figure 5: Model 2 - Front modelling

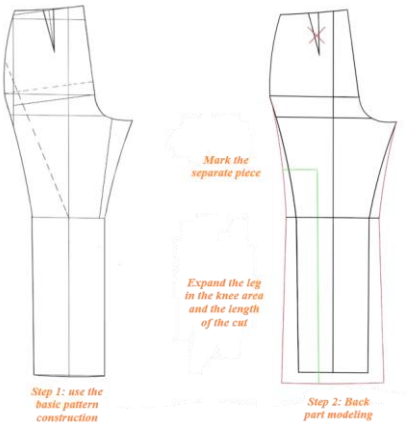

Figure 6: Model 2 - Back modeling

For this model, a strap with dimensions of 50 x 3.5 cm is constructed, and a pocket with dimensions of 20 x 20 cm is constructed.

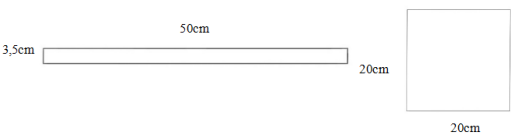

Figure 7: Strap and pocket construction for Model 2

4. CONCLUSION

Fashion is a cultural practice that creates and perpetuates social conditions in addition to reflecting them. The jumpsuit is a timeless piece that designers are constantly reinventing, from its utilitarian origin as unintentionally stylish air force wear to its dominance on the hedonistic disco dance floors of the 1970s to its current role as a mainstay of street style. These days, it has become an essential piece in any wardrobe and gives a multitude of styling options, whether it is worn elegantly, casually, or extravagantly. The jumpsuit is a timeless fashion icon because of its effortless ability to blend comfort, style, confidence, and adaptability. Its attractiveness lies not only in its appearance but also in its ability to reflect the evolution of fashion. The aim of this paper was to construct two models of jumpsuits, inspired by their significance for the upliftment and liberation of women. At the same time, our intense was to point out the importance of knowing basic construction and its modeling, since knowing this, every idea for creation can be designed.

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APPLICATION OF ELASTIC AND SOFT CONDUCTIVE MATERIAL ON TEXTILES

Review scientific paper
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ABSTRACT: *Examples of application of elastic (stretchable) and soft conductive material on textiles are given. The elasticity and softness of the conductive material is a logical adaptation to the frequent change of shape in textiles, especially clothes, which is one of the main differences from the classic substrate in electrical engineering. Those materials can be conductive textiles, but also materials that are applied with elastic (stretchable) textiles.*

Keywords**:** *Electronics on textiles, elastic (stretchable) and soft conductive material on textiles.*

PRIMENA ELASTIČNOG I MEKANOG PROVODNOG MATERIALA NA TEKSTILU

APSTRAKT: *Dati su primeri primena elastičnog (istegljivog) i mekanog provodnog materiala na tekstilu. Elastičnost i mekoća provodnog materijala je logično prilagođavanje čestoj promeni oblika kod tekstila, posebno odeće, što je i jedna od glavnih razlika od klasične podloge u elektrotehnici. Ti materijali mogu biti provodni tekstil ali i materijali koji se primenjuju uz elastični (istegljivi) tekstil.*

Ključne reči*: Elektronika na tekstilu, Elastični (istegljiv) i mekan provodni material na tekstilu.*

1. INTRODUCTION

Application of elastic (stretchable) and soft conductive material on textiles is one of the directions of development of electronics (in a broader sense including the entire range of radio waves) on textiles [1-9]. The term elastic (stretchable) and soft conductive material implies the use of polymers and composites, but also classic non-textile materials such as rubber [10]. This also includes the use of ordinary non-conductive textiles as well as the use of some non-textile materials such as polypropylene (PP) [11] and kapton (polyimide film) [12]. As fibers, some non-textile materials also become part of textiles. Elastics

(stretchable) and soft non-conductive textiles are also very important because they represent the substrate for the conductive material and must follow it in changing dimensions. It should also be noted that the use of flexible classical printed circuit boards (PSB) is also expanding [13].

2. SOME APPLICATION EXAMPLES

Figure 1. shows the need for synchronized spreading of the substrate and conductive material, in this case conductive ink.

Figure 1: Stretchable and washable filter ink printed directly on stretchable textile [14]

Figure 2. shows the application of nanowires and polymers.

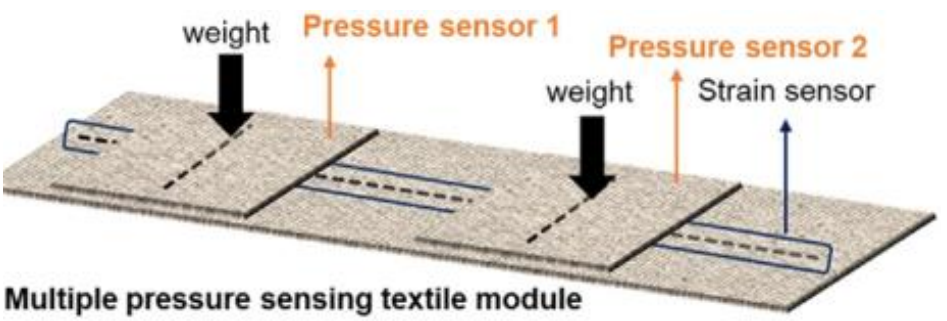

Figure 2: Mechanically robust textile-based strain and pressure multimodal sensors using metal nanowire/polymer conducting AgNW/PEDOT conducting fiber [15]

Figure 3 shows the application of a commercial stretch textile and conductive wire in a meander that can follow the stretching of the substrate.

Figure 3: Interconnect ribbon with conductive yarn that was attached onto ribbon in a horse-shoe shape [16]

Figure 4 shows an example of a commercial Stretch sensor.

Figure 4: Stretch sensor, *Holland shielding resistive systems BV* for measurement of small movements [17]

Figure 5 is an example of a sensor made of commercial materials, easy-to-build.

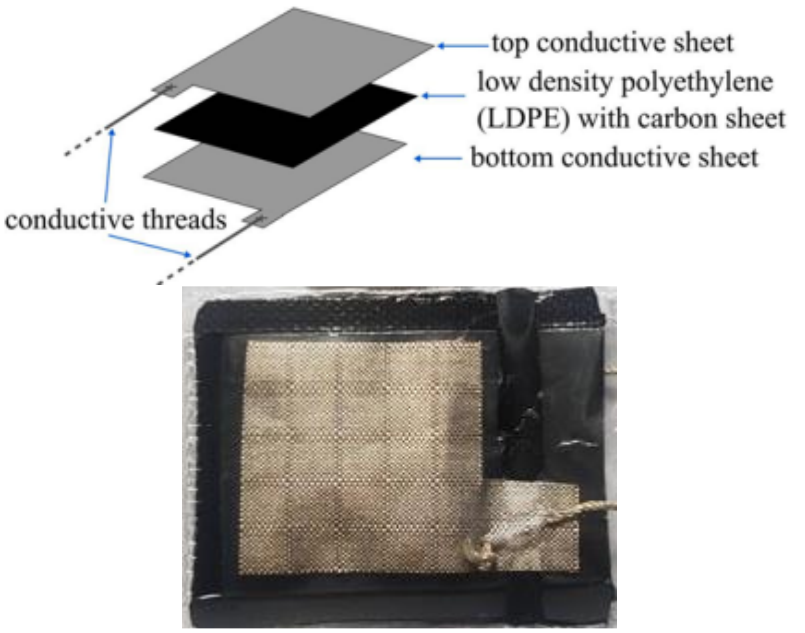

Figure 5: Easy-to-Build Textile Pressure Sensor [18]

Figures 6 and 7 shows the application of composites in sensor construction.

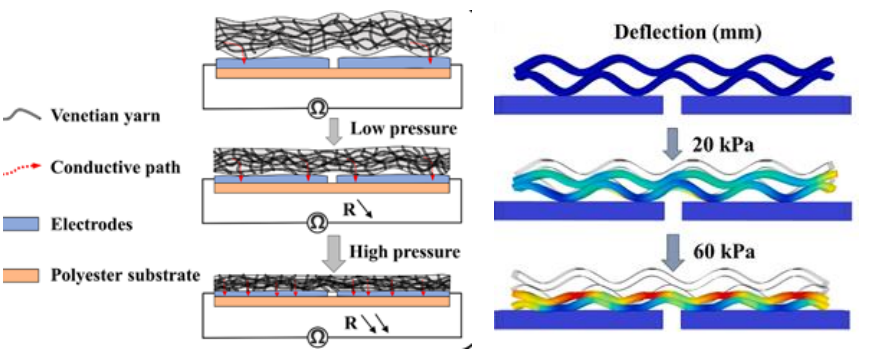

Figure 6: All textile-based robust pressure sensors for smart garments [19]

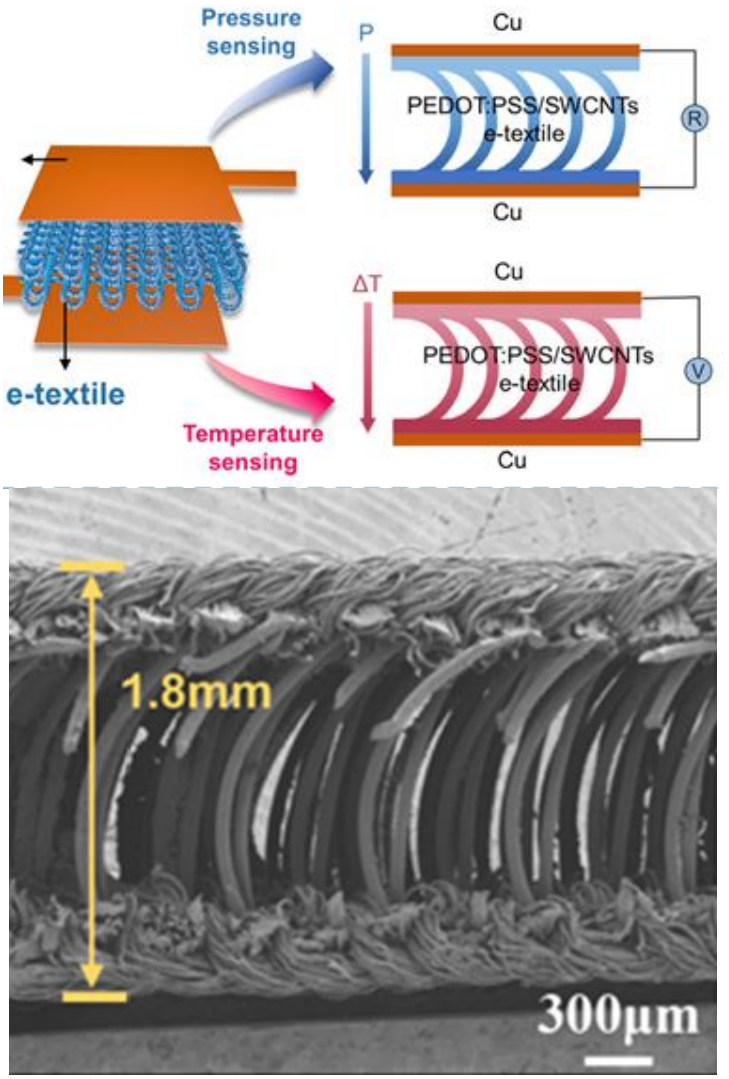

Figure 7: Dual-mode textile sensor based on PEDOT: PSS/SWCNTs composites for pressure–temperature detection [20]

3. CONCLUSION

Elastic (stretchable) and soft conductive material on textiles are increasingly present with further development. In this case, the application of new materials, but also the application of commercial materials that enable easier production, is prominent.

ACKNOWLEDGEMENT

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THE INFLUENCE OF COTTON FABRIC STRUCTURE ON THE STRENGTH OF SEWING SEAMS

Original scientific paper
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ABSTRACT: *The goal of this work was to examine the influence of stitch density and different linear density of weft threads (20, 30 and 50 tex) on the seam strength of cotton fabrics. The following stitch densities were tested: 3, 4, 5, 6 and 7 stitches/cm. For seam strength testing, fabric samples were prepared according to the provisions of the ISO 13935-1 standard. The samples were sewn in the warp and weft directions with the selected seam type marked 1.01.01/301. The obtained results show that the seam strength values, for all samples, increase with increasing stitch density and linear density of the thread per weft. From the results, it can be concluded that denser stitches strengthen the seam structure itself. This makes the seams more resistant to external forces. The results obtained show that weft yarns, with a larger cross-section, more intensively resist the tearing forces acting on them in the seams. Also, the results of the research show that the warp yarn, which had a larger number of twists, more intensively resists the tearing forces acting on them in the seams. Defining these parameters represents a significant contribution for manufacturers of quality clothing. Knowing this data, it is possible to project in advance the intensity of the forces to which the seams may be exposed in clothing, without reducing their quality.*

Keywords: *density of stitched seams, strength of sewn seams, structure and fabric density.*

UTICAJ STRUKTURE PAMUČNIH TKANINA NA ČVRSTOĆU ŠAVOVA ZA ŠIVENJE

APSTRAKT: *Cilj ovog rada bio je istražiti uticaj gustine šivaćih uboda i različitih podužnih masa potkinih niti (20, 30 i 50 tex) na čvrstoću šavova za šivenje kod pamučnih tkanina. Ispitivane su sledeće gustine uboda: 3, 4, 5, 6 i 7 uboda/cm. Za ispitivanje jačine šavova, uzorci tkanina su pripremljeni prema propisima standarda ISO 13935-1. Uzorci su šiveni u pravcu osnove i u pravcu potke odabranim tipom šivaćeg šava oznake 1.01.01/301. Dobijeni rezultati pokazuju da vrednosti jačine šavova, za sve uzorke, rastu sa povećanjem gustine šivaćih uboda i podužne mase niti po potki. Iz rezultata se može zaključiti da gušći šivaći ubodi jačaju samu strukturu šavova. Time se šavovi jače suprostavlja delovanju spoljašnjih sila. Dobijeni rezultati pokazuju da se pređe za potku, sa većim poprečnim presekom, intezivnije u šavovima suprostavljaju prekidnim silama koje deluju na njih. Takođe, rezultati istraživanja pokazuju da se pređe za osnovu, koja je imala veći broj uvoja, u šavovima intezivnije suprostavljaju prekidnim silama koje deluju na njih. Definisanje ovih parametara predstavlja značajan doprinos za proizvođače kvalitetne odeće. Poznavanjem ovih podataka mogu se unapred projektovati intenziteti sila kojima se šavovi mogu u odeći podvrgnuti a da se pri tome ne naruši njihov kvalitet.*

Ključne reči: *gustina uboda šivenih šavova, jačina šivenih šavova, struktura i gustina tkanina.*

1. INTRODUCTION

The fashion market today requires the manufacturer of fabrics of very quick answers to the requests of clothing manufacturers. Namely, clothing manufacturers, often have requirements for fabrics of spares surface masses. Fabric producers, to some extent, can quickly respond to the change in the fine of the pope and density threads. It can be easily done on modern machines for making fabrics today. The available fabrics on the market are today different structural characteristics. Therefore, in this paper, samples of fabric testing aged three different fines per weft [1]. The fastest rating of fabric properties is to the tender. The feeler is a completely sensory experience in which the fabric touches with the fingers [2]. Every fabric, for making clothes, is complex material and its structure depends on a large extent and the properties of clothing. Therefore, many researchers deal with the analysis of structure of fabrics that is considered one of the basic parameters that contributes to the dominant physical and qualitative properties of woven material [3].
Woven textile materials are most often combined with seams in sewing technique. A large number of factors affects the quality of seams. Some of them are a type of material, types of sewing stitches, a density of sewing threads, a flexure threading point, sewing speed, and shape of the peak of needles as well as other elements of sewing machines participate.
According to research [4], damage that appear on the seams of clothing products, due to stretching in an interval of 68.3% on pants, where they are largest, blouses at 9.4%, jackets at 8.4%, skirts at 8.4% and up to 5.0% in the dresses. The largest deformations occur at the

seat seam of pants and skirts and moving at the interval of up to 59.1%. At the seam at the joint of the sleeves and the back of the shirt and a jacket up to 27.1%, on the side seams of pants, dresses and skirts go to value 9.0%. On the seam in the middle of the rear of the upper garments, 3.9% and on the other seams on the clothes move at the interval of up to 0.9%.

Seam is one of the most important parameters of clothing, because it combines pieces of fabric and gives a garment of the ultimate form. The proper selection of fabric, the sewing thread and the types of seams greatly affect the comfort of users and aesthetic and functional requirements of clothing. This area is largely explored by giving a new approach to predicting sean quality and strength [5].

Fabric producers are necessary to know how the structure of the fabric affects the quality of the seam or sliding or seam [6]. For this reason, a large number of tests of the influence of seam types, density of stitches and stitching the quality of seams in terms of stitches and suture glides. [7] today is mainly investigated: influence of density or seam structure on linen fabrics on the characteristics of seamless sutures and stitches [8]; Complex dynamic interactions between fabric performance, parameters of sewing and stitching processes [9]; Efficiency, strength and elongation of seams on cotton fabrics [10]; Influence of various sewing parameters, such as: type of sewing thread, suture type, stitches as well as stitch density on the seamless strength [11]; Influence of density of stitches and seam types on the properties of moisture management in seams [12]; Durability of clothing depending on the strength of seams, density of stitches, aesthetic appearance and sutures on the various fabric structures [13]; The impact of different stitch densities to achieve proper and adequate suture quality [14]; Influence of raw material composition fabrics, fineness of the sewing and sewing parameters for sewing on the characteristics of clothing seam; the reasons that lead to poor quality sutures in sewing; Resistance to sliding seams of unbalanced fabrics; The appearance of the seam depending on the types of cookies for sewing, fabric and sting [15].

From the available literature it can be seen that problems in sewing are not easy to solve. Therefore, a large number of parameters, such as: fibers, yarn, fabric structure, sewing thread, seams and sewing machines must be examined specifically in almost all sewing conditions that differ mostly [16].

2. MATERIALS AND METHODS

The study investigated the influence of stitch density and three different linear densities of weft yarns (20, 30, and 50 tex) on seam strength in cotton fabrics. For the purpose of the research, various cotton fabric samples were produced under industrial conditions on a "Vamatex" loom equipped with a rapier weft insertion system. The loom was also fitted with an electronic warp let-off system. The working width of the loom was 190 cm. All samples were produced on the same loom in order to eliminate the influence of different machines on the sample production.

The selected fabric for the research was made of 100% cotton, with a plain weave structure, using warp yarns with a linear density of 40 tex and a warp density of 24 threads/cm for all samples. The warp and weft yarn densities were measured according to the EN 14971

standard. The weft density was 25 cm^{-1}. Three different weft yarn linear densities were used for the test samples: 20 tex, 30 tex, and 50 tex. The linear densities of both warp and weft yarns were determined according to the SRPS ISO 7211-5 and SRPS F.S2.511 standards. The surface mass of the woven fabrics was determined according to the EN ISO 2286-2 standard for all fabric samples produced for testing.

For the seam strength testing, the fabric samples were prepared in accordance with the ISO 13935-1 standard. Laboratory test samples, measuring 350 x 700 mm, were cut in both the warp and weft directions for all fabrics. Each sample was then folded in half so that the longer side was parallel to the folded edge. The samples are shown in Figures 1 and 2. Figure 1 shows a laboratory sample sewn with a seam and marked cutting lines. Figure 2 shows a test sample with shaded areas indicating the parts to be cut out.

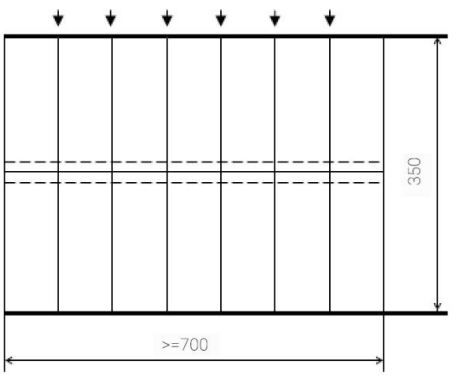

Figure 1: Laboratory sample sewn with a seam and marked cutting lines

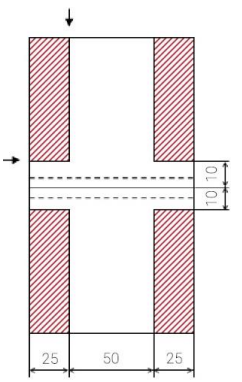

Figure 2: Test sample with shaded areas to be cut out

The samples were then sewn in the warp and weft directions using the selected seam type designated as 1.01.01/301 according to the international standard ISO 4916. The samples were sewn on a universal sewing machine manufactured by Juki, model DDL-5550, using stitch type 301. The following machine parameters were set: sewing speed – 3,000 stitches/min; needle size – Nm 90; presser foot pressure – 2.8 N; and thread tension – 0.50 N. The stitch density was adjusted on the machine in five increments. After measurement on the sewn seams, the stitch densities obtained were 3, 4, 5, 6, and 7 stitches/cm. The same type of thread was used for sewing all test samples, with a fineness of Tt 20.7 tex, a tensile strength of 23.37 N, and an breaking elongation of 15.17%. The thread was made of 100% polyester fibers. Seam strength testing was carried out using a Tenso Lab 3 dynamometer, series 2512A, manufactured by the Italian company Mesdan S.p.A. Figure 3 shows the dynamometer with a prepared sample placed in the grips for testing.

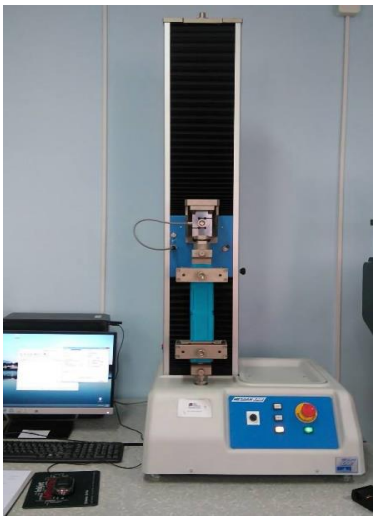

Figure 3: Prepared sample for testing

Table 1 presents the different samples of the tested fabrics sewn using seam type 1.01.01/301.

Table 1: Different fabric samples sewn in the warp and weft directions using seam type 1.01.01/301

Sample marking	Weave structure	Linear density T_t (tex)		Yarn type		Density		Surface mass m ($g \cdot m^{-2}$)
		for warp	for weft	for warp	for weft	warp d_{wa} (cm^{-1})	weft d_{we} (cm^{-1})	
A	Plain 1/1	40	50	100 Co	100 Co	24	25	232,52
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

3. RESULTS AND DISCUSSION

The tensile strength of the fabric samples was measured in both the warp and weft directions. The seams of the test samples were sewn parallel to the warp and weft directions. This was done to determine the influence of different weft yarn thicknesses on seam deformation. The seams were sewn with varying stitch densities in order to evaluate the effect of stitch density on seam strength. Based on the measurements and the investigation of the influence of different fabric densities on the mechanical properties of the seams, the obtained results are presented. Table 2 shows the results of seam tearing strength measurements on fabric samples in both the warp and weft directions.

Table 2: Results of seam tearing strength measurements on fabric samples in the warp and weft directions

Sample marking	Stitch density [cm^{-1}]	Seam breaking values in the warp direction		Seam breaking values in the weft direction	
		Force [N]	Elongation [%]	Force [N]	Elongation [%]
A	3	330	11.98	308	11.20
	4	362	11.75	332	10.78
	5	373	12.48	345	11.56
	6	395	11.28	359	10.25
	7	409	11.43	372	10.39
B	3	284	11.36	261	10.42
	4	315	10.83	286	9.85
	5	335	12.36	302	11.13
	6	340	11.14	312	10.22
	7	361	10.39	322	9.28
C	3	272	13.47	247	12.25
	4	288	11.27	257	10.06
	5	299	9.46	265	8.37
	6	313	9.97	275	8.75
	7	330	9.39	287	8.16

Figure 4 shows a comparison of the seam breaking forces for samples A, B, and C in the warp and weft directions.

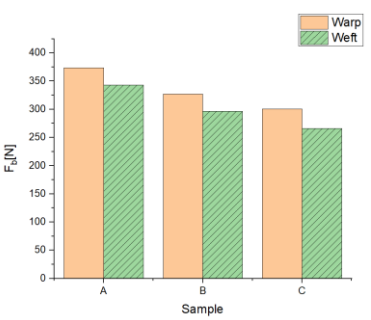

Figure 4: Comparison of seam breaking forces for samples A, B, and C in the warp and weft directions

The study examined three types of cotton fabric samples that differed only in the linear density of the weft yarn used. For sample A, the weft linear density was Tt 50 tex; for sample B, it was Tt 30 tex; and for sample C, it was Tt 20 tex. All samples were sewn with the following stitch densities: 3, 4, 5, 6, and 7 stitches/cm. During research, it was observed that the main difficulties in testing seam strength arose from different types of damage occurring during seam tearing. All observed damage types can be classified as: fabric rupture, fabric rupture near the clamp, fabric rupture near the seam, sewing thread breakage,

thread pullout, or any combination of these. For the testing, only samples that failed at the seam itself were considered as relevant results. All other samples where failure occurred in other areas were excluded from analysis in this study.

The obtained results show that the stitch density significantly affects the seam breaking force. Specifically, observing the values presented in Table 2 for sample A in the warp direction, it can be seen that the seam breaking forces increase with increasing stitch density. This occurs because denser stitches strengthen the seam structure itself, enabling the seam to better resist the action of external forces. The seam breaking forces also increase for samples B and C as stitch density increases, for the same reason as in sample A. In other words, denser stitches reinforce the seam structure, and with increasing stitch density, the force resisting external deformation forces also increases. The same pattern is observed in the weft direction. For example, the values shown in Table 2 for sample A in the weft direction demonstrate that seam breaking forces increase with increasing stitch density due to the strengthening effect of denser stitches, which enable the seam to better resist external forces. The results also indicate that the linear density of the weft yarn influences the seam breaking force. Specifically, the weft yarn linear densities are Tt 50 tex for sample A, Tt 30 tex for sample B, and Tt 20 tex for sample C. Regarding the seam breaking force in the warp direction, the highest force values for all stitch densities are observed in sample A, which is made from the thickest weft yarns. These values decrease for sample B, which is made from thinner weft yarns compared to sample A. The seam breaking forces are lowest for sample C, which is made from the thinnest yarns in comparison to both samples B and A.

Expressed in percentages, the average seam breaking force for sample B decreases by 12.52% compared to the average seam breaking force of sample A. The average seam breaking force for sample C decreases by 19.64% compared to sample A. Furthermore, the average seam breaking force for sample C decreases by 8.14% compared to sample B.

Regarding the seam breaking force in the weft direction, the highest force values for all stitch densities are observed in sample A, followed by a decrease in sample B, with the lowest values in sample C. Expressed in percentages, the average seam breaking force for sample B decreases by 13.58% compared to the average seam breaking force of sample A. The average seam breaking force for sample C decreases by 22.44% compared to sample A. Additionally, the average seam breaking force for sample C decreases by 10.25% compared to sample B.

The results show that weft yarns with a larger cross-sectional area more effectively resist the breaking forces acting upon them.

When comparing the seam breaking forces for the same samples in the warp and weft directions, it can be seen that the seam breaking forces in the weft direction are lower. For sample A, the seam breaking forces in the weft direction are 8.19% lower compared to those in the warp direction. For sample B, the seam breaking forces in the weft direction are 9.30% lower compared to the warp direction. For sample C, the seam breaking forces in the weft direction are 11.38% lower compared to the warp direction.

The results also indicate that warp yarns, which have a higher number of twists, more effectively resist the breaking forces acting upon them.

4. CONCLUSION

The obtained results show that the stitch density for sewing has a significant impact on the seam breaking force. Specifically, when observing the seam breaking force values for all samples in the warp direction, it is evident that these values increase with the increase in stitch density. This occurs because denser stitches strengthen the seam structure itself, allowing the seams to better resist external forces. The same effect is observed in the weft direction.

The results also show that the linear density of the weft yarn affects the seam breaking force. In the warp direction, the highest force values for all stitch densities are observed in sample A, followed by a decrease in sample B, with the lowest values in sample C. The same pattern is visible in the weft direction, where the highest breaking forces are recorded for sample A, followed by lower values for sample B, and the lowest for sample C. These results indicate that weft yarns with a larger cross-sectional area more effectively resist the breaking forces acting on them.

When comparing the seam breaking forces of the same samples in the warp and weft directions, it can be seen that the seam breaking forces are lower in the weft direction. The results also show that warp yarns, which have a higher number of twists, more effectively resist the breaking forces acting on them.

Overall, the results demonstrate that the seam strength values for all samples increase with the increase in both the stitch density and the linear density of the weft yarn. Defining these parameters represents a significant contribution for manufacturers of quality clothing. This data enables them to proactively design the necessary production parameters. By understanding these factors, manufacturers can anticipate the intensity of forces to which seams may be subjected in garments without compromising their quality.

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PROTECTIVE CLOTHING AND THERMAL STRESS: INTEGRATING COOLING SYSTEMS FOR ENHANCED PERFORMANCE

Review scientific paper
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ABSTRACT: *In recent years, the increase in legal regulations concerning personal protection has been accompanied by a significant growth trend in the protective clothing industry. The primary purpose of protective clothing is to provide a barrier against biological, chemical, physical, and mechanical hazards in the relevant field. However, to support the wearer's performance, these garments are also expected to maintain the body's thermal balance and manage thermal stress, depending on environmental conditions. Research in this area has shown that protective clothing used in various fields often exhibits insufficient heat and moisture transfer ability, indicating deficiencies that need to be addressed based on their intended use. Particularly in products where textile material properties are prominent and effective—such as firefighter suits, CBRN suits, and surgical gowns—there is significant potential for development and application, making them attractive for innovative studies. Within the scope of this study, the active and passive cooling systems engineered to enhance heat transfer and decrease thermal stress will be given in detail.*

Keywords: *protective clothing, thermal stress, heat transfer, cooling system.*

ZAŠTITNA ODEĆA I TERMIČKI STRES: INTEGRACIJA SISTEMA ZA HLAĐENJE ZA POBOLJŠANE PERFORMANSE

APSTRAKT: *Poslednjih godina, povećanje zakonskih propisa u vezi sa ličnom zaštitom prati značajan trend rasta u industriji zaštitne odeće. Primarna svrha zaštitne odeće je da pruži barijeru protiv bioloških, hemijskih, fizičkih i mehaničkih opasnosti u relevantnoj oblasti. Međutim, da bi se podržale performanse korisnika, od ove odeće se takođe očekuje da održava termičku ravnotežu tela i upravlja termičkim stresom, u zavisnosti od uslova okoline. Istraživanja u ovoj oblasti su pokazala da zaštitna odeća koja se koristi u različitim oblastima često pokazuje nedovoljnu sposobnost prenosa toplote i vlage, što ukazuje na nedostatke koje treba rešiti na osnovu njihove namenjene upotrebe. Posebno kod proizvoda gde su svojstva tekstilnog materijala istaknuta i efikasna - kao što su vatrogasna odela, HBRN odela i hirurške mantile - postoji značajan potencijal za razvoj i primenu, što ih čini atraktivnim za inovativne studije. U okviru ove studije, detaljno će biti dati aktivni i pasivni sistemi hlađenja projektovani za poboljšanje prenosa toplote i smanjenje termičkog stresa.*

Ključne reči: *zaštitna odeća, termički stres, prenos toplote, sistem hlađenja.*

1. INTRODUCTION

In high-temperature environments, perspiration constitutes the primary physiological mechanism through which the human body dissipates excess heat. However, the efficiency of this process is markedly limited under conditions of elevated relative humidity (RH). In such contexts, adequate ventilation and air cooling become critical for effective heat transfer and for maintaining acceptable indoor air quality [1].

According to the theory of body heat balance, thermal comfort is achieved when the amount of heat produced by the body is approximately equal to the amount of heat lost to the environment. In extremely hot environments or during high activity levels, the only way for the body to lose excess heat is through the evaporation of sweat from the body. The rate of evaporative cooling depends on the vapor pressure gradient between the skin surface and the environment, as well as the speed of air movement in the microclimate [2].

Thermal stress can significantly reduce productivity and increase the risk of heat-related injuries for workers. Since thermal stress poses a threat to workers' lives, health, and productivity, the researchers have especially focused on various personal cooling systems [3]. These systems have found a wide range of applications in everyday life for the deliberate reduction of skin and body temperature. Various garments have been developed to assist sweating in hot environments (e.g., astronauts and military personnel) or to enhance athletic performance [4]. Each of these methods is effective in reducing thermal stress, alleviating physiological strain, and increasing work duration. However, lack of mobility, limited cooling capacity, logistics, cost, and other factors limit their practical applications [3]. Based on these requirements, this study presents an overview on thermal stress, cooling effect, and protective clothing specifically designed for use in this field.

2. PROTECTIVE CLOTHING

Protective textiles are a part of technical textiles that are defined as comprising all those textile-based products which are used principally for their performance or functional properties rather than their aesthetic or decorative characteristics. Protective clothing refers to garments and other fabric-related items designed to protect the wearer from harsh environmental effects that may result in injuries or death [5].
The global industrial protective clothing market size was reported by Grand View Research as USD 18,350.7 million in 2022 and is projected to reach USD 31,178.0 million by 2030, growing at a CAGR of 6.9% from 2023 to 2030. Rising awareness regarding the importance of preventing work-related fatal accidents is likely to propel market growth [6].
Protective clothes can be classified such as thermal protection, flame protection, chemical protection, mechanical impact protection, radiation protection, biological protection, electrical protection and wearer visibility in terms of end-use functions. Besides, according to end use applications, they can be also classified as industrial protective textiles, agricultural protective textiles, military protective textiles, civilian protective textiles, medical protective textiles, sports protective textiles and space protective textiles [7]. The relationship is indicated in Figure 1.

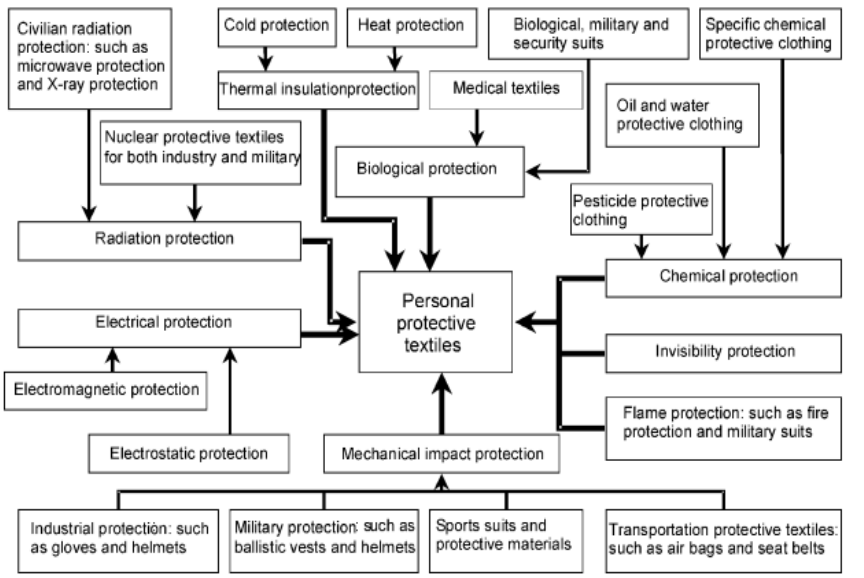

Figure 1: Classification of protective textiles [7]

In addition to specific barrier property, it is also expected to support the wearer's performance by maintaining the body's thermal balance and thereby managing thermal stress, particularly in relation to the environmental conditions in which they are used.

Clothing is the first protection against the heat wave coming from the outside. However, its thermal efficiency is time-limited due to its thermal properties, and it has the disadvantage of impairing metabolic heat and sweat evaporation. Therefore, harsh burns or heat stress can occur. There is a need for clothing solutions that eliminate overheating and automatically cool the body [8]. Therefore, it becomes essential to incorporate an additional layer into these specialized garments that provides a cooling effect, enhancing thermoregulatory performance by reducing thermal stress without compromising protective functionality.

3. THERMAL STRESS

Heat stress caused by prolonged exposure to high temperatures poses a significant threat to various biological systems. In other words, thermal stress refers to the strain on materials or biological tissues due to temperature changes. In humans, it is the physiological strain resulting from exposure to heat or cold; here, heat stress involves the body struggling to maintain a healthy core temperature. These issues require the development and implementation of effective heat stress reduction strategies [9]. Risks associated with heat exposure are more prevalent in some occupational environments, but implementation of heat management systems remains inadequate [10]. Adaptation and mitigation measures are essential to protect the workforce with the aim of improving both worker health and productivity [11]. Heat-related health and productivity consequences lead to social and economic costs for workers due to temporary or permanent health and quality of life impairments [12]. Future research should adopt an interdisciplinary approach that integrates social, economic, environmental, and technical dimensions to reduce these impacts [13].
Textile-based studies on heat stress reduction have been conducted. Nanoporous PE-containing fabrics have been shown to support directional moisture transport and maintain cooling performance while improving comfort [14]. Nanoporous polyethylene fabrics with ZnO nanoparticles were designed to reflect solar radiation while conducting body heat, reducing skin temperature by 5-13°C compared to cotton [15]. Flexible thermoelectric clothing has been found to maintain skin comfort at ambient temperatures up to 40°C under mild airflow [16]. Hybrid studies integrating thermoelectric micro/nanowires in fabrics have achieved cooling of approximately 5°C [17]. Shape memory polymers and dynamic structures allow textiles to actively adapt porosity or surface area in response to heat or humidity, improving ventilation and moisture management [18]. Textiles containing smart phase change materials can absorb heat during increasing temperature and release it when it is colder, supporting thermal comfort [19].

4. PERSONAL COOLING SYSTEMS

Personal cooling systems (PCS) currently play a crucial role in reducing thermal stress for athletes, firefighters, and workers exposed to extreme environmental conditions. These cooling garments can be categorized into two main types: passive and active systems. Passive garments do not rely on mechanical or electrical equipment; the main types include

textile-based cooling and phase change materials (PCM). Well-known types of active garments are air-cooled garments (ACG), liquid-cooled garments (LCG), garments based on gas expansion and thermoelectric cooling devices, and hybrid cooling garments [Table 1; 20].

Air-cooled garments are relatively lightweight and help keep garments dry. They rely on the body's own mechanism (sweating) to dissipate heat, thus eliminating the risk of overcooling that may occur with other types of garments. However, in high relative humidity conditions, the efficiency of air-cooled garments decreases due to saturated ambient air. It has been concluded that pre-cooling the air before it passes over the skin can enhance performance in hot environments. The independence of air-cooled garments depends on battery-powered fans. Due to the low energy consumption of these fans, some garments can operate continuously for up to 12 hours. The air gap between the skin and the inner layer of the garment affects heat transfer. To maximize sweat evaporation, a gap between the skin and garment is recommended [2, 21, 30-37].

Liquid-cooled garments are heavier than those utilizing air-cooling. If the tubes embedded in the garment are compressed, fluid circulation may be disrupted. A cooling control mechanism is suggested to adjust cooling fluid temperature and circulation based on changes in skin temperature. However, if physical activity decreases, unwanted body heat loss may occur, leading to discomfort. In humid environments, if water circulates in the gap between the skin and the protective equipment, vapor formation may cause skin burns. If the ambient air temperature exceeds that of the coolant, the coolant may gain heat from the surroundings, reducing cooling efficiency [2, 3, 21, 38-42].

Garments based on gas expansion are lightweight but are believed to offer very limited operational duration compared to other cooling garments. Apart from the short operating time, the main issue is the release of CO_2 exhaust into the environment. If multiple users wear such garments in enclosed spaces, CO_2 concentration may reach hazardous levels [3, 43]. Garments based on thermoelectric cooling include thermoelectric devices (TEDs), which are solid-state refrigeration devices that can pump heat against a temperature difference and thus are suitable for personal cooling applications in hot environments. They have attracted significant interest in recent years due to their solid-state nature, readily adjustable cooling power and temperature, small form factor, and lightweight [16, 44-46].

Hybrid systems combine passive and active cooling techniques [21, 28, 47-55]. The most common hybrid garments are liquid-air cooling or phase change material-air cooling. Hybrid garments are generally more efficient than garments using a single technology. The effective cooling duration of a hybrid garment will be limited by the shortest duration among its combined technologies. For phase change material (PCM)-air cooled garments, PCM defines the effective cooling time [21]. The melting temperature of the PCM significantly affects the performance of the protective garment [55]. Once the PCM melts, the hybrid garment will continue to provide reduced cooling with the help of fans. However, these garments tend to be bulkier compared to conventional single-technology garme.

Table 1: Comparision of personal cooling sytems

		Mechanism	Advantages	Disadvantages	Applications	References
Passive Systems	Textile-based cooling	Reduce thermal resistance between skin and environment	Light, comfortable, effective in a wide range of environments, easy to maintain	Potential of skin irritation, expansive effectiveness, negligable cooling effect in very hot or humid environment	Sports, industrial, regular wear, military	4, 21-26
	Phase change materials-cooling	PCM absorbs heat during phase-change from solid to liquid	Simple, flexible, portable	Short cooling duration, limited capacity, possible flammability	Sports, industrial workers, outdoor use	2, 21, 27-29
Active Systems	Air-cooling	Air circulation to achieve perspiration evaporate	Long-term cooling, easy manufacturing, cheap, lightweight, high-performance, thermal comfort	Requires power, need to use porous fabric structure to enhance cooling effect	Sports, military, outdoor workers, firefighting	2, 21, 30-37
	Liquid-cooling	Cooling liquid circulation	Highly efficient, easy manufacturing, high cooling capacity	Large, heavy, risk of liquid leakage, requires power, potential safety risk, short operating time, risk of undesired body heat loss	Military, firefighting, industrial workers	2, 3, 21, 38-42
	Gas-cooling	Gas expansion cools via evaporation of liquified CO_2	No moving parts, cost-effective, portable, no external power required, lightweight	Limited cooling duration, potential toxicity	Outdoor activities	3, 43
	Thermoelectric cooler	Electric current creates hot and cold sides through the Peltier effect	Efficient cooling, small, lightweight, simple structure, lack of vibration, stable, noiseless and reliable, controllable	Expensive materials and manufacturing, high commercialization difficulty, limited cooling capacity, no larger and wearable active cooling garment, dissipating heat to the environment, brittle	Sports, military, outdoor recreation, consumer electronics	16, 44-46

Hybrid Systems	Combining active and passive systems	Improved performance, enhanced cooling efficiency, adaptability to various conditions, extended duration	Logistical complexity, increased weight and size, higher cost, require careful integration of components	Military, industrial, emergency response	21, 28, 47-55

3. CONCLUSION

The use of personal cooling garments can significantly improve human comfort and health in various hot environments. At the same time, they contribute to global efforts to reduce energy consumption and environmental pollution. However, an increasing number of factors must be considered due to the complexity of environmental conditions and human needs, while designing the cooling garments. These factors can be examined in three main groups: environment, clothing, and human body. Therefore, it is crucial to explore newly developed strategies that aim to improve the cooling properties of materials while also ensuring them lighter, more cost-effective, more environmentally friendly, and easier to manufacture. Additionally, personal cooling systems should be optimized and designed to include a wider range of parameters for assessing the performance of different personal cooling technologies.

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SESSION II

TEXTILE AND FASHION DESIGN

A COMPARATIVE ANALYSIS OF CREATIVE WORKFLOWS IN WOVEN, KNITTED, AND PRINTED TEXTILE DESIGN

Original scientific paper
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ABSTRACT: *In all design disciplines, textile design encompasses the generation of creative ideas for specific purposes followed by their structured realization through defined processes. Core techniques such as knitting, weaving, and printing—or hybrid combinations of these-are employed to create textile surfaces. The initial stages of the design process-concept development, exploration of sources of inspiration, and the generation of creative ideas-are common across all design fields. However, the implementation phase varies depending on the production technologies and surface design techniques employed. This study adopts a cognitive perspective to comparatively examine the creative workflows of textile designers working in the weaving, knitting, and printing sectors. It aims to highlight the differences in the activities, inspirational styles, and the creative idea generation and reflection processes of textile designers, depending on the sector in which they operate. Utilizing ethnographic methodology, the study analyzes the experiences and perspectives of 30 textile designers-10 from each sector-employed in leading textile companies in Türkiye. Through a systematic coding process, emergent concepts, patterns, and expressions were identified, leading to the categorization of key thematic areas. A decoding process was applied to uncover the meanings attributed by participants to various concepts, leading to the categorization of emerging themes, concepts, patterns, and meaningful expressions. The findings reveal that textile designers adapt their creative workflows in response to the aesthetic, technical, and commercial demands of their respective sectors. In the sub-theme of sector-specific definitions of textile design, it was found that each sector conceptualizes textile design differently: for weaving designers, textile design involves creating fabrics according to customer demands; for knitting designers, it focuses on developing value-added designs; and for printing designers, it is about designing fabrics in alignment with current fashion trends. In the sub-theme of sources of inspiration, all participants reported drawing inspiration from nature. However, sector-specific differences were observed in the frequency of using other sources, such as culture, architecture, art, social events, current issues, design, and technology. Regarding methods of reflecting inspiration in design, all participants employed techniques such as simplification, modification, and addition. However, differences*

emerged across sectors in the use of methods such as direct reflection, abstraction, and relating to other sources.

Keywords: *Textile design, Woven fabric design, Knit fabric design, Printed fabric design.*

UPOREDNA ANALIZA KREATIVNIH RADNIH TOKOVA U DIZAJNU TKANOG, PLETENOG I ŠTAMPANOG TEKSTILA

APSTRAKT: *U svim dizajnerskim disciplinama, dizajn tekstila obuhvata generisanje kreativnih ideja za određene svrhe, nakon čega sledi njihova strukturirana realizacija kroz definisane procese. Osnovne tehnike poput pletenja, tkanja i štampe – ili hibridne kombinacije ovih – koriste se za kreiranje tekstilnih površina. Početne faze procesa dizajniranja – razvoj koncepta, istraživanje izvora inspiracije i generisanje kreativnih ideja – zajedničke su u svim oblastima dizajna. Međutim, faza implementacije varira u zavisnosti od proizvodnih tehnologija i korišćenih tehnika dizajniranja površina. Ova studija usvaja kognitivnu perspektivu kako bi uporedno ispitala kreativne tokove rada dizajnera tekstila koji rade u sektorima tkanja, pletenja i štampe. Cilj joj je da istakne razlike u aktivnostima, inspirativnim stilovima i procesima generisanja kreativnih ideja i refleksije dizajnera tekstila, u zavisnosti od sektora u kojem posluju. Koristeći etnografsku metodologiju, studija analizira iskustva i perspektive 30 dizajnera tekstila – po 10 iz svakog sektora – zaposlenih u vodećim tekstilnim kompanijama u Turskoj. Kroz sistematski proces kodiranja identifikovani su novi koncepti, obrasci i izrazi, što je dovelo do kategorizacije ključnih tematskih oblasti. Primenjen je proces dekodiranja kako bi se otkrila značenja koja učesnici pripisuju različitim konceptima, što je dovelo do kategorizacije novih tema, koncepata, obrazaca i značajnih izraza. Rezultati otkrivaju da dizajneri tekstila prilagođavaju svoje kreativne tokove rada kao odgovor na estetske, tehničke i komercijalne zahteve svojih sektora. U podtemi sektorskih definicija dizajna tekstila, utvrđeno je da svaki sektor drugačije konceptualizuje dizajn tekstila: za dizajnere tkanja, dizajn tekstila podrazumeva kreiranje tkanina prema zahtevima kupaca; za dizajnere pletenja, fokusira se na razvoj dizajna sa dodatom vrednošću; a za dizajnere štampe, radi se o dizajniranju tkanina u skladu sa aktuelnim modnim trendovima. U podtemi izvora inspiracije, svi učesnici su izjavili da crpe inspiraciju iz prirode. Međutim, primećene su razlike specifične za sektor u učestalosti korišćenja drugih izvora, kao što su kultura, arhitektura, umetnost, društveni događaji, aktuelna pitanja, dizajn i tehnologija. Što se tiče metoda odražavanja inspiracije u dizajnu, svi učesnici su koristili tehnike kao što su pojednostavljivanje, modifikacija i dodavanje. Međutim, pojavile su se razlike među sektorima u korišćenju metoda kao što su direktna refleksija, apstrakcija i povezivanje sa drugim izvorima.*

Ključne reči: *Dizajn tekstila, Dizajn tkanih materijala, Dizajn pletenih materijala, Dizajn štampanih materijala.*

1. INTRODUCTION

Design is a creative act that involves generating original ideas and transforming these ideas into concrete results through a planned process. According to Cross [1] design is one of the highest forms of human intelligence and a phenomenon related to the capabilities of the mind. The design process follows the same pattern whether it involves the design of a new oil refinery, the construction of a cathedral, or the writing of Dante's Divine Comedy. Design is concerned with creating things that people want with building patterns that have value. These things must be thought about and made. Design involves a thinking activity and an executive activity [2].

According to Ambrose and Harris [3] the design process consists of the stages of definition, research, idea generation, prototype creation, selection, implementation, and learning. Moreover Wilson [4] explains that the design process includes the stages of identifying needs, research, idea generation, design development, and final design. From a general perspective, design actions develop in a sequence that progresses from abstract mental processes to concrete physical events [5].

The design process, due to its creative nature, has always been subject to scrutiny and has been at the centre of efforts to systematize and to scientific it [6]. In his book ‘Design Methods: Seeds of Human Futures’ [7], Jones made significant contributions regarding design methods referring the intuitive and rational approaches as the black box and the glass box respectively [8].

Some theorists such as Osborn, Gordon, Matchett, and Broadband imply that the most valuable part of the design process goes inside the designer's head and partly out of reach of his conscious control [8]. These 'creativity' theorists place themselves in opposition to the rationalists of designing. This irrational approach is called the 'black box' approach. This approach to the design process is shaped by irrational, mystical, and subconscious elements. The designer interacts with images, intuitions, and emotions from the subconscious, beyond conscious thoughts.

In contrast, the majority of theorists line up with entirely explicable design process where externalized thinking and rationalized assumptions are used. This 'glass box' approach attempts to reveal what happens in the designer's mind using psychological research [5], through which the objectives, variables, and criteria are fixed in advance. In this case the designer has full knowledge of what he is doing and why he is doing it. The designer follows through a planned sequence of analytical, synthetic and evaluative steps and cycles until he recognizes the best of all possible solutions. As to sum up, it would not be wrong to say that the multifaceted nature of design requires the process to be approached not only through intuitive or rational methods but in a more holistic manner.

With the criticism that the decreasing role of the designer in the act of designing and the purely pragmatic approaches hinder creativity and originality, cognitive science, which was heavily debated especially in the 1970s, has greatly influenced design. In this context, a third approach, known as cognitive approaches, has emerged [8]. According to Uluoğlu [9] the vagueness of intuitive approaches and the excessive confidence of algorithmic approaches in the belief that everything can be explained were insufficient to describe the

design process. Cognitive models based on information theory were applied to this field to explain the design process.
The understanding of the textile design process and the improvement of design practices necessitate the adoption of cognitive approaches that allow for the externalization of designers' mental processes. In this study, by adopting a cognitive approach and based on the data obtained from interviews conducted with textile designers, the question of whether there are differences in the activities/styles of inspiration, creative idea generation, and reflection depending on the sector in which textile designers work has been explored.

2. TEXTILE DESIGN PROCESS

Textile design, in its context, refers to the process of creating a product through concrete design decisions after abstracting mental processes which are conducted with a specific purpose in mind. Here, design decisions are made at every stage of the process, from the identification of a need/requirement to the generation of initial design ideas, design development, and the final product. Questions such as which fibres should be used in yarn, which yarns should be used in fabric, what weight of fabric should be produced, what colours should the yarn or fabric be produced in, what fabric structures should be used, and what finishes should be applied need to be reviewed and planning should be done in the design process [4].
The textile-design process typically begins with a concept development phase in which creative ideas are transformed into tangible products. During this phase, designers create a theme based on the target audience, intended use, and current trends. Sources of inspiration can come from a wide range of areas such as nature, art, cultural motifs, or technological advancements. At this stage, the designer outlines the basic elements of the design by selecting colour palettes, textures, and materials. A good start is the key to a successful final product, both aesthetically and functionally. Once the concept is determined, the technical applications of the design are initiated. During this phase, processes such as hand drawings, digital design tools, and material selection progress together. The types of fabrics and weaving or knitting techniques define the character of the design, while colour choices and pattern placement are also integrated into this process. Prototyping is a critical stage in bringing the design to life; here, the aesthetic and technical details of the design are tested. After evaluating the prototypes, necessary revisions are made, and the final design is prepared for production. In textile design, fabrics are created using weaving, knitting, printing, and mixed techniques. At the beginning of the design process, concept determination, research of sources of inspiration, and creative idea generation are common processes. However, in the application phase, the process varies according to the production technology and patterning techniques used.
In woven design, jacquard weaving machines, which operate with a power system, and frame-based twill and eccentric machines are utilized. With weaving design, it is possible to obtain complex and creative woven surfaces with different structural characteristics (simple and compound), and various weaving structures (plain weave, twill, satin basic weaves, and derivative weaves).

In knit design, aesthetic and functional fabrics can be produced using different patterning techniques on weft and warp knitting machines. Coloured patterned fabrics are created with Jacquard systems; different derivative weaves with loop, hanger, and skip combinations; structural patterns through loop transfer; pile or loop surfaces with extra yarn usage; Fully-Fashion surfaces by increasing and decreasing the width of the fabric; and Intarsia surfaces with the use of different coloured threads in different areas of the fabric.
While structural solutions are developed in woven and knit design, in textile printing design, creative solutions applied to the surface are developed according to the fabric's raw material, texture, and intended use. Various printing techniques (direct printing, discharge printing, reserve printing, transfer printing, rotary printing, film printing, screen printing, and special printing effects) can be used to aesthetically and technically enhance the surface of woven or knit fabrics.

3. METHODOLOGY

This study employs an ethnographic research design, one of the qualitative research methods, to investigate the design behaviours of textile designers. Data were collected through semi-structured interviews, participant observation, and document analysis. The data collection was conducted between December 7, 2023, and May 13, 2024, in the textile companies where the participants were employed. A total of 22 companies located in Kahramanmaraş, Tekirdağ, Kırklareli, Bursa, and Istanbul were included in the study.
Since textile design encompasses the process of fabric design using weaving, knitting, and/or printing techniques, maximum variation sampling—one of the purposive sampling strategies—was deemed appropriate for this research. The study group consisted of 30 textile designers working in Turkey, with expertise in either printing (n=10), weaving (n=10), or knitting (n=10). Efforts were made to ensure a balanced distribution of participants in terms of areas of expertise and gender. Among the participants specializing in printing, four focused solely on digital printing, while six were involved in both digital and rotary printing design. Of the weaving designers, four specialized in dobby weaving, three in jacquard weaving, and three in both techniques. Among the knitting designers, three specialized in flat knitting, three in raschel knitting, and four in circular knitting.
Ethical approval for the study was obtained from the Ethics Committee of Ankara Hacı Bayram Veli University. An informed consent form was prepared to ensure participants' voluntary and conscious participation in the study. This form provided clear and comprehensible information regarding the purpose, duration, methods, potential risks, benefits, and alternatives of the research. It also informed participants of their right to withdraw from the study at any time without any negative consequences.
Using ethnographic methods, the collected data were examined in depth based on the participants’ experiences and perspectives. To reveal the meanings participants attributed to various concepts, a coding process was implemented. During this process, themes, concepts, patterns, and meaningful expressions were analyzed and categorized. The coded data were described within context and presented as coherent wholes. To enhance the credibility of the interpretations, direct quotations from participants’ narratives were

included and presented in italics and quotation marks. NVivo 15 software was used to support the data analysis process. Based on the identified themes, conceptual explanations were made in relation to the cultural and social context of the participants.

In accordance with ethical principles, the data collected from the study group were anonymized and coded as “W” for weaving designers, “K” for knitting designers, and “P” for printing designers, followed by participant numbers (e.g., W1, K2, P3). The demographic information of the participants is presented in Table 1.

The research findings are based on data collected within the scope of the doctoral thesis titled "A Research on Defining the Process of Inspiration, Idea Generation, and Reflection Ideas in Textile Design."

Table 1: Demographic information of the participants

Participant Code	Demographic Information				
	Gender	Age	Education	Specialization	Experience
W1	Male	36	High School	Weaving	15 years
W2	Female	28	Master’s Degree	Weaving	2 years
W3	Female	39	Associate’s Degree	Weaving	20 years
W4	Female	41	Bachelor’s Degree	Weaving	21 years
W5	Female	22	Bachelor’s Degree	Weaving	5 months
W6	Female	35	Bachelor’s Degree	Weaving	10 years
W7	Male	58	Bachelor’s Degree	Weaving	36 years
W8	Male	52	High School	Weaving	24 years
W9	Male	47	High School	Weaving	20 years
W10	Female	40	High School	Weaving	25 years
K1	Female	21	High School	Knitting	2 years
K2	Male	54	Primary School	Knitting	38 years
K3	Male	55	High School	Knitting	32 years
K4	Male	47	Bachelor’s Degree	Knitting	22 years
K5	Female	34	High School	Knitting	11 years
K6	Female	30	Bachelor’s Degree	Knitting	8 years
K7	Male	53	High School	Knitting	30 years
K8	Male	55	Bachelor’s Degree	Knitting	33 years
K9	Male	54	Master’s Degree	Knitting	33 years
K10	Female	45	Bachelor’s Degree	Knitting	15 years
P1	Female	32	Bachelor’s Degree	Printing	7 years
P2	Female	33	Bachelor’s Degree	Printing	5 years
P3	Male	42	Bachelor’s Degree	Printing	20 years
P4	Female	44	Bachelor’s Degree	Printing	11 years
P5	Female	30	Associate’s Degree	Printing	10 years
P6	Female	32	Bachelor’s Degree	Printing	10 years
P7	Female	50	High School	Printing	30 years
P8	Female	39	Bachelor’s Degree	Printing	6 years
P9	Female	33	Master’s Degree	Printing	7 years
P10	Male	37	Bachelor’s Degree	Printing	12 years

4. FINDINGS

4.1. Definitions of Textile Design Based on Areas of Specialization

For the purpose of defining textile design, participants were asked the following questions: "What do you think textile design is?" and "Can you describe the work you do every day in the field of textiles?" The codes and frequency counts derived from the data obtained from three working groups are presented in Table 2.

Table 2: Definitions of textile design based on areas of specialization

Code	Specialization			Total (n=30)
	Weaving (n=10)	Knitting (n=10)	Printing (n=10)	
Customer	5	2	2	9
Fashion	0	2	4	5
Innovation	3	2	1	5
Adding value	0	3	0	3
Imagining	0	1	2	3
Touching life	1	0	2	3
Appealing to tastes	0	2	1	3
Reflecting ideas	1	0	1	2
Creating	1	0	0	1

According to Table 2, weaving designers defined textile design within the framework of the codes customer, innovation, touching life, reflecting ideas, and creating. Among these, the customer code has the highest frequency in this group. In relation to this code, the definition of "designing fabrics in accordance with customer demands" emerges.
Knitting designers defined textile design within the framework of the codes adding value, customer, appealing to tastes, fashion, innovation, and imagining. Among these, the code with the highest frequency is adding value. In relation to this code, the definition of “developing designs by adding value” emerges.
Printing designers defined textile design within the framework of the codes fashion, customer, imagining, touching life, innovation, appealing to tastes, and reflecting ideas. Among these, the code with the highest frequency is fashion. In relation to this code, the definition of “designing fabrics in line with fashion trends” emerges.
The following are selected statements from some of the participants.
"*In my point of view, textile design is about creating designs that align with the goals of the client. In other words, it involves designing in accordance with the intended use and the specific needs of the* ***customer***" (W6 – Recording 00:29).
"*In terms of raw materials, processes, yarns used, and construction, the fabrics are essentially the same. However, because a design and* ***added value*** *are incorporated and since there is no real competitor offering the same, they are able to sell a fabric worth 5*

dollars for 10 euros. Therefore, design is, in general, a highly influential and significant element in our lives" (K3 – Recording 03:08).
"*Designs are created in response to current fashion trends, desires, and preferences. I focus on designing women's outerwear. Typically, designs are developed according to the prevailing trends and preferences in* ***fashion***" (P4 – Recording 00:46).
It has been concluded that participants define mostly textile design as designing fabrics that meet customer demand. It has been evident that designers strongly focus on customer, added value, and fashion. However, in the literature, textile design is seen from different perspectives. Steed and Stevenson [7] emphasizing the techniques used, define the process of fabric design as the creation of fabrics using knitting, weaving, printing, and mixed techniques. Wilson [4] on the other hand, emphasizes the commercial aspect and defines it as the process of designing and producing a specified number of commercially viable fabrics according to a predetermined timeline.

4.2. Sector-Based Distribution of Sources of Inspiration

In order to identify the sources of inspiration used in the design process, participants were asked the question: “What sources of inspiration do you draw upon when creating your designs?” The distribution of the sources of inspiration used by the participants according to sector is presented in Table 3.

Table 3: Sector-based distribution of sources of inspiration

Utilized Sources of Inspiration	Specialization			Total (n=30)
	Weaving (n=10)	Knitting (n=10)	Printing (n=10)	
Nature	10	10	10	30
Culture	6	6	8	20
Architecture	6	7	5	18
Art	5	6	7	18
Social Events and Issues	3	3	1	7
Design	1	1	2	4
Technology	0	0	2	2

According to Table 3, it was found that participants from the weaving, knitting, and printing sectors all drew inspiration from nature in their design processes. It was also observed that culture, art, and design were more frequently utilized as sources of inspiration in the printing sector, while architecture was more commonly referenced in the knitwear sector. Social events and issues appeared to be more prominent in the weaving and knitting sectors compared to printing. Additionally, technology was identified as a source of inspiration exclusively in the printing sector.
The "Nature" code refers to drawing inspiration from natural elements such as flowers and animals; the "Culture" code refers to drawing inspiration from the cultures of various societies; the "Architecture" code refers to drawing inspiration from architectural structures; the "Art" code refers to drawing inspiration from works of art such as paintings

and sculptures; the "Social Events and Issues" code refers to drawing inspiration from events affecting society, such as pandemics and wars; the "Design" code refers to drawing inspiration from fields such as interior design, graphic design, textile, and fashion design; and the "Technology" code refers to drawing inspiration from technological elements such as artificial intelligence.
The sources of inspiration used by the participants were visualized as a word cloud in the NVivo program (See Figure 1).

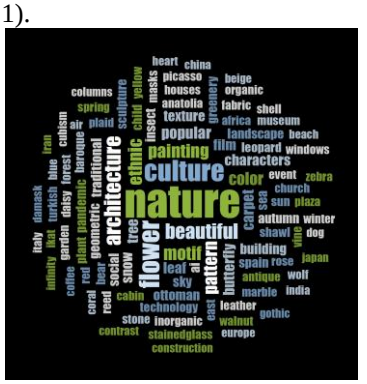

Figure 1: Sources of inspiration used by textile designers

The following are selected statements from some of the participants.
"*I use **nature** more frequently in my designs. (...) Being in nature inherently makes people feel better. For this reason, we need to incorporate elements of nature into our designs for home living as well. (...) I have noticed that products with these elements tend to sell better, and as a result, I make a conscious effort to incorporate them more into my designs*" (W5 – Recording 16:48).
"*When dining at a restaurant or traveling abroad, one is often influenced by the **architecture**. In fact, one's perspective is crucial. Being able to possess a vision is something truly valuable. It is essential to be knowledgeable in all aspects. When you have knowledge, your ability to analyze takes on an entirely new dimension. (...) Architecture, of course, offers a wide variety of motifs. In historical structures, particularly in both Turkey and abroad, in Europe, etc., you can find very diverse motifs. You can draw inspiration from them and, for example, apply the design of a motif you admire onto fabric*"(K3 – Recording 25:53).
"*We draw inspiration from ethnic **cultures**. These include Turkish motifs, Indian motifs, and many others, each differing significantly. In particular, motifs with African origins serve as a source of inspiration for us*" (P7 – Recording 22:57).
It is possible to categorize the sources of inspiration used by designers into different categories. For example, Eckert [11] categorized the sources of inspiration used by designers in the textile industry as clothing, photographs of clothing, works of art, and natural objects. Additionally, he mentioned that many themes are inspired by nature, and that designers often collect portable physical objects such as leaves and seashells, use photographs, or work from memory.

4.3. Ways of Accessing Sources of Inspiration According to Sector

In order to determine the ways of accessing sources of inspiration, participants were asked the questions: “From which media do you obtain your sources of inspiration? Which media do you use, such as trend books, periodicals, various catalogues, trade fairs and seminars, websites, personal photo archives, etc.?” The distribution of the ways participants access sources of inspiration by sector is presented in Table 4.

Table 4: Ways of Accessing Sources of Inspiration According to Sector

Utilized Sources of Inspiration	Specialization			Total (n=30)
	Weaving (n=10)	Knitting (n=10)	Printing (n=10)	
Trade Fairs	6	8	7	21
Websites	6	5	10	21
Trend Books	6	4	8	18
Personal Photo Archives	6	4	4	14
Company's Design Archives	3	0	0	3
Physical Stores	1	1	1	3
Fashion Shows	0	1	2	3
Social Media	2	1	0	3
Fabric Catalogs	1	1	0	2
Fashion Magazines	1	1	0	2
Art Books	0	1	1	2
Nature Trips	0	0	1	1
Yarn Catalogs	1	0	0	1
Color Catalogs	1	0	0	1
Seminars	0	0	1	1
Exhibitions	0	0	1	1
Artificial Intelligence	0	0	1	1

According to Table 4, among the most preferred access methods based on areas of expertise, websites are the most prominent in the printing sector, while trade fairs are most favored in the knitwear sector. In the weaving sector, trade fairs, websites, trend books, and personal photo archives are used equally.

The following are selected statements from some of the participants.

"***Fairs*** *definitely have an impact. When you attend a fair, there are things that others have imagined before you, things that you may not have seen or conceived of yourself. These ideas serve as a source of inspiration for you*" (W8 – Recording 12:12).

"*Each year, we attend trade* ***fairs*** *such as Pitti Immagine Filati and Pitti Immagine Uomo held in Italy, participating as visitors. Pitti Immagine Filati, in particular, provides valuable insights, especially in terms of yarn and knitwear, and serves as a significant source of inspiration for us*" (K9 – Recording 32:45).

"*We often visit* ***stores*** *and attend* ***fairs****. The photos we take during these visits are collected in a shared archive, not for personal use but as a department resource. Everyone*

contributes photos, and sometimes we visit specific stores on our own. We primarily visit the stores of our clients, those we work with. Additionally, we participate in international fairs. As I mentioned, we always ***archive the photos*** *we take in one place. When we start working on a collection, we first refer to this archive. If it does not provide enough inspiration, we explore a few* ***websites*** *like WGSN, as I mentioned earlier. We conduct searches to see what we can gather and what could add value to our work*" (P1 – Recording 13:51).

Table 5: Methods of Reflecting Sources of Inspiration in Design by Sector

Reflection Methods		Specialization			Total (n=30)
		Weaving (n=10)	Knitting (n=10)	Printing (n=10)	
Realistic (One-to-one)	One-to-one reflection is applied.	7	9	7	23
	One-to-one reflection is not applied.	3	1	3	7
Simplification	Simplification is applied.	10	10	10	30
Abstraction	Abstraction is applied.	7	10	8	25
	Abstraction is not applied.	3	0	2	5
Changes and Additions	Changes and additions are applied.	10	10	10	30
Association with Different Sources	Association with a different source is applied.	10	7	10	27
	Different sources are not combined.	0	3	0	3

4.4. Methods of Reflecting Sources of Inspiration in Design by Sector

In order to determine how ideas derived from sources of inspiration are reflected in designs, participants were asked the following questions: "Do you ever directly translate the source into your designs without altering its elements? Do you simplify the elements of the source and reflect them in your designs? Do you abstract the source and reflect it in your designs? Do you modify, reorganize, or add new elements to the source and incorporate them into your designs? Do you combine a source of inspiration with other sources when creating a design?" The distribution of methods used by participants to reflect ideas from sources of inspiration into their designs according to sector is presented in Table 5.

According to Table 5, the methods of simplification and changes/additions were preferred by all participants a1 the weaving, knitting, and printing sectors. The one-to-one reflection method was found to be more commonly preferred in the knitting sector. The abstraction method was applied by all knitting designers, while some printing and weaving designers did not use this method. The method of associating different sources was applied by all printing and weaving designers, while some knitting designers did not apply this method. The following are selected statements that illustrate the use of the realistic (one-to-one) representation method.

“That is related to the structure of the design. (...) The client may want it that way, so I cannot add anything there and I need to depict the leaf exactly as it is, for example. However, if the client grants me that freedom, I can transform the leaf in such a way that something entirely different emerges” (P9 – Recording 28:18).
"*I don't believe that one-to-one representation is the true purpose of design. For instance, incorporating a heart motif into a design with a love theme feels cliché to me. It's not what I would consider genuine design*" (W2 – Recording 34:04).
"*Yes, I focus on direct representations of nature. (...) I consider myself more of a realist artist, like Michelangelo or Leonardo. I don’t feel like a surrealist like Miró or Kandinsky. I am a perfectionist in my designs, meaning that it is important to me for them to resemble reality and to be natural*" (K9 – Recording 46:52) (See Figure 2).

Figure 2: A design example applying the Realistic method (K9 – Visual document)

The following are selected statements that illustrate the use of the simplification method.
"*If my source of inspiration is, for example, a digital design or image, and I am requested to create a rotation print, I am compelled to adapt it accordingly. This involves reducing the colors, simplifying the design, and minimizing the coverage to create a more streamlined output. Essentially, I have to adjust the design to fit the requirements of the printing unit*" (P1 – Recording 26:41).
"*Cost is an important factor, so we need to simplify it. The production technique, the yarn, and the weaving time, all of these aspects must be considered. Everything actually points towards simplification. The customer's style also directs this process*" (K10 – Recording 33:15).
"*For example, clients may present highly complex pattern references, or the images or colors we initially base our designs on can be quite intricate. If necessary, we simplify these elements, either to meet the client's request or to align with the specific group we are incorporating into that season's collection*" (W1 – Recording 27:30) (See Figure 3).

Figure 3: An example of a woven design applying the Simplification method (W1)

The following are selected statements that illustrate the use of the abstraction method.
"*I generally enjoy creating abstract works by using geometry. (...) For instance, if our theme is a human face, I always choose to focus on a well-known and iconic subject. I often work with geometric interpretations of figures such as the Mona Lisa, Marilyn Monroe, or James Dean. In other words, I have typically explored the geometric representations of famous artists' portraits*" (K9-Kayıt 49:23).
"*In general, I don't think I tend to approach my work in this way. (...) For example, if I am trying to convey something happy, I wouldn't simply draw a square. I don't do that*" (W5-Kayıt 26:51).
"*Abstraction is possible, but it is generally not highly supported. (...) I believe that few people are able to understand abstraction. Perhaps my colleagues can grasp it, but when it reaches the outside world, when it enters the lives of ordinary people, those who do not work in this field, it can often be perceived as excessive or, for some, even meaningless. (...) First, I immerse myself in the visual I observe, thoroughly examining its details through a careful process of scrutiny. Then, I combine it with my own style. When transforming it into an abstract form, it is crucial that my work remains recognizable. I believe I can abstract it by interpreting it in a unique style that I conceive in my mind* "(P2-Kayıt 31:45) (See Figure 4).

Figure 4: An example of a print design that applies the Abstraction method (P2)

The following are selected statements that illustrate the use of the changes and additions method.

"*I can change the color, modify the pattern, or alter the materials used* " (W2- Kayıt 41:08).
"*I can add elements to the flower. In other words, I try to create different motifs while the flower is present. (...) The crochet patterns can be altered. The design can be different; in other words, the design elements can be changed. New motifs can be added*" (K8- Kayıt 19:26).
"*For example, if I start with a flower design, I may remove the flower's petal and replace it with a finer flower or perhaps add a geometric shape to give the design a different touch, changing it in that way. (...) Design elements certainly change. First, I examine its size, appropriateness in terms of scale. Then, I proceed with the design process. As I mentioned, I might remove or add elements like petals or flowers, or incorporate something different, such as geometric, animal, or ethnic motifs. (...) I make such changes. Finally, I move on to the variation and coloring stage, where I apply colors that are in line with current fashion trends or suit the customer's style*" (P5- Kayıt 34:40) (See Figure 5).

Figure 5: A print design using the Changes and Additions method (P5)

The following are selected statements that illustrate the use of the association with different sources method.
"*Absolutely. As I mentioned at the beginning of our conversation, we consume so much now, and everything has already been done. As designers, we are not supernatural beings. Now, what we do is take something and match it with another, place one thing onto another, and sometimes it even becomes quite humorous. For example, it never would have occurred to me in the past to combine flowers with leopard print, but now I find myself creating a leopard design, and when you look closely, you realize that it's actually a leopard formed from flowers"* (P10-Kayıt 52:35).
"*Honestly, it doesn't work. When you draw from too many sources, it becomes very complex. (...) Incorporating too many actions or objects onto a fabric can create chaos in the design*" (K3-Kayıt 43:51).
"*Yes, we refer to them as patchwork fabrics. (...) The contrasts are more important. It depends on the customer's request. They may suggest, for example, that you can combine flowers with geometry, or even place a human figure alongside a flower. They guide you. And you design accordingly, in a way that can be appropriately applied and visible on the fabric*" (W9-Kayıt 28:12) (See Figure 6).

Figure 6: An example of a jacquard woven design employing the Association with Different Sources method (W9– Visual document)

Eckert and Stacey [12] examined the performance of knitwear designers, classifying their intentions and the relationship between their final designs and inspiration derived from Iranian carpets. The methods designers use to reflect their sources of inspiration are classified as: realistic (one-to-one) reflection, conscious simplification, abstraction, modifications and additions, and relating to a different source [12-13]. This classification has also been applied in the studies of Petre, Sharp, and Johnson [14] and Strickfaden, Stafiniak, and [15] where it is noted that designers applied at least one of these transformation methods.

5. CONCLUSION

As in all design disciplines, textile design involves the generation of creative ideas directed toward a specific purpose and the realization of these ideas through a structured process. In textile design, fabrics are created using knitting, weaving, printing, or mixed techniques. The initial stages of the design process include concept development, investigation of sources of inspiration, and the generation of creative ideas, which are common to all areas of specialization. The implementation phase, however, varies depending on the production technologies and surface design techniques used.

In this study, in response to the question “Do textile designers' activities/styles of inspiration, creative idea generation, and idea representation differ according to the sector they work in?”, data were collected under the sub-themes of sector-specific definitions of textile design, sources of inspiration, access routes to inspirational resources, and methods of representation. The findings indicate that textile designers adopt different approaches depending on the aesthetic, technical, and commercial requirements of the sector in which they operate.

Within the sub-theme of textile design definitions by sector, it was found that textile design is defined differently a1 weaving, knitting, and printing fields. According to weaving designers, textile design involves creating fabrics in line with customer demands; for

knitting designers, it is about developing designs that add value; and for printing designers, it means designing fabrics in accordance with fashion trends. These differing definitions indicate that designers approach the process from distinct perspectives, shaped by the specific nature and workflow of their own discipline.

In the sub-theme of sources of inspiration used by sector, it was found that all participants drew inspiration from nature. However, sector-specific differences were observed in the frequency of use of other sources such as culture, architecture, art, social events and issues, design, and technology. It was observed that culture, art, and design were more commonly utilized as sources of inspiration in the field of printing. Architectural sources were found to be more prominent in the field of knitting, which may be attributed to the structural and aesthetic characteristics of knitting techniques that parallel the forms found in architectural design. Social events and issues were more frequently emphasized in weaving and knitting compared to printing. Technological sources, on the other hand, were utilized exclusively in the field of printing.

In the sub-theme of access to sources of inspiration by sector, websites were found to be the most commonly used access channels in the field of printing. This finding indicates the sector's strong adaptation to digitalization. In the knitting field, trade fairs emerged as the most preferred access route. This can be explained by the opportunities fairs provide for physically experiencing the tactile qualities of knitted fabrics and establishing more effective connections through face-to-face interaction. In weaving, it was determined that trade fairs, websites, trend books, and personal photo archives were used equally. This suggests that the weaving field benefits from a balanced combination of traditional and innovative resources.

While striving to produce original designs, textile designers also take into account factors such as client expectations and production limitations. They apply their inspirational sources through various methods including realistic (one-to-one) representation, intentional simplification, abstraction, modification and addition, and association with other sources. Although these techniques, as categorized by Eckert and Stacey (2003), are implemented in practice, they are often applied in an intuitive or unconscious manner.

In the sub-theme of methods of reflecting sources of inspiration by sector, it was found that all participants employed the methods of simplification and making modifications and additions. The realistic (one-to-one) reflection method was predominantly preferred in the knitting field. All knitting designers applied the abstraction method, whereas some designers in printing and weaving did not. The method of associating different sources was employed by all designers in printing and weaving, while some knitting designers did not adopt this approach.

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ARTIFICIAL INTELLIGENCE IN FASHION DESIGN: A CASE STUDY ON SLEEPWEAR DESIGN

Professional paper
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ABSTRACT: *Generative artificial intelligence (AI) is rapidly transforming the fashion industry, enabling designers to generate visual concepts from textual inputs or data with unprecedented speed and flexibility. This study investigates the application of generative AI in sleepwear design, focusing on autumn–winter two-piece pyjamas comprising a long-sleeved top and long pants. Drawing on findings from a comprehensive consumer survey that identified pyjamas and nightgowns as the most preferred sleepwear types, the study integrates user preferences directly into the design process. A generative AI model (HiDream-I1 FULL) was employed to create visual sleepwear designs based on text prompts, illustrating the potential of AI-assisted design to align product development more closely with consumer demand.*

Keywords: *Artificial intelligence (AI), fashion, design, sleepwear, consumer behaviour, consumer perceptions.*

VEŠTAČKA INTELEGENCIJA U MODNOM DIZAJNU: STUDIJA SLUČAJA O DIZAJNU ODEĆE ZA SPAVANJE

APSTRAKT: *Generativna veštačka inteligencija (VI) brzo transformiše modnu industriju omogućavajući dizajnerima da kreiraju vizuelne koncepte iz tekstualnih unosa ili podataka sa neviđenom brzinom i fleksibilnošću. Ova studija istražuje primenu generativne veštačke inteligencije u dizajnu odeće za spavanje, sa fokusom na dvodelne pidžame za jesen-zimu koje se sastoje od majice dugih rukava i dugih pantalona. Oslanjajući se na rezultate sveobuhvatnog istraživanja među potrošačima, koje je pokazalo da su pidžame i spavaćice najpoželjniji tipovi odeće za spavanje, studija direktno integriše korisničke preferencije u proces dizajna. Generativni model veštačke inteligencije (HiDream-I1 FULL) korišćen je za kreiranje vizuelnih dizajna odeće za spavanje na osnovu tekstualnih opisa, ilustrujući potencijal dizajna uz pomoć veštačke inteligencije da bolje uskladi razvoj proizvoda sa potrošačkom potražnjom.*

Ključne reči: *Veštačka inteligencija (VI), moda, dizajn, odeća za spavanje, ponašanje potrošača, percepcije potrošača.*

1. INTRODUCTION

In recent years, artificial intelligence (AI) has gained significant traction in the fashion industry and has found its way into almost every segment of the fashion value chain. From trend forecasting and consumer behaviour analysis to concept and design development, material sourcing, 3D garments prototyping, production, logistics, and retail, AI-driven tools are enhancing creativity, streamlining the design process, improving sustainability, and better meeting consumer demands [1-3]. Fashion companies are leveraging this technology to create better-selling designs, reduce marketing costs, hyper-personalize customer communications, and accelerate processes. AI also has the potential to reshape supply chains, store operations, and organizational support functions [4]. Machine learning algorithms can process vast amounts of data to identify emerging styles and predict demand, enabling designers to make informed decisions that align with evolving consumer preferences [5, 6]. Generative AI, in particular, holds promise for reimagining garment design by producing novel patterns, textures, and colour combinations that push the boundaries of traditional aesthetics [7, 8]. Although AI is increasingly integrated into the fashion industry, its application in the field of sleepwear design remains largely unexplored. Sleepwear (also known as nightwear, sleep clothing, or nightclothes), often overlooked in fashion innovation, typically consists of comfortable and loose-fitting garments designed for sleeping or relaxing at home. Available in a variety of styles, designs, colours, and textiles, sleepwear caters to different preferences and climates. However, meeting consumer expectations for comfort, style, and seasonally appropriate features makes sleepwear design a complex challenge. According to our 2024 survey conducted in Slovenia, pyjamas and nightgowns (nighties or nightdresses) are the most popular types of sleepwear [9]. Despite the importance of this category, the potential of generative AI to support sleepwear design - particularly in aligning products with consumer preferences - remains largely unexplored.

This study addresses that gap by investigating the integration of generative AI into the design process for autumn-winter sleepwear. Guided by the results of a comprehensive consumer survey - which identified pyjamas and nightgowns as the most favoured sleepwear types - the research focuses on developing two-piece pyjamas composed of a long-sleeved top and long pants [9]. By employing a generative AI model (HiDream-I1 FULL) to generate design visuals from text prompts, this study demonstrates how AI can be leveraged to create consumer-informed sleepwear designs that respond to seasonal needs and market demand.

2. METHODOLOGY

2.1. Survey data

The first part of study was conducted in 2024 and explores various aspects, including consumer perceptions and preferences regarding sleepwear textiles, details, colours, and styles [9]. A quantitative research study was conducted by interviewing to examine consumer habits related to wearing sleepwear. A random sample was used in data collection. The total number of respondents who carried out a survey was 437. Of these,

298 respondents answered the question regarding gender and age, 4 % (11) were men and 95 % (283) were women, 4 respondents were unspecified regarding gender.

2.2. AI-driven generation of sleepwear design images

The initial experimental phases involved exploring image generation models. We began with trials in various generative environments, such as Stable Diffusion and Flux, which are two leading models in this space [10]. We used Stable Diffusion 3.5 LARGE model in our previous research [11], which is why we opted to use new open-source image generative foundation model HiDream-I1 FULL [12]. These models enable designers to create images from text prompts, which is why we used the survey results to guide prompt generation.

Figure 1: The complete Hidream-I1 FULL workflow pipeline inside ComfyUI

HiDream-I1 [12] is a 17 billion parameter open-source model, released under the MIT licence [13], released in April 2025, which features a new sparse diffusion transformer, making it function differently from established diffusion-based models like Dall-E3, Midjourney or Stable Diffusion. It also has a companion E1 model, which allows for semantic understanding of natural language image editing in the style of current commercial models like Imagen4, which runs inside Gemini 2.5 Pro and GPT-Image-1, which runs inside ChatGPT. Using advanced text encoders like LLAMA 3.1 allows for complex prompt interpretations with advanced spatial reasoning, while the sparse diffusion transformer allows for usage of specialized sub-models, resulting is high adherence to longer detailed prompts, which demonstrates leading performance in benchmarks like GenEval and DPG-Bench [14]. It’s also important to know that unlike Flux.1 (which is an extremely capable T2I model), HiDream allows for negative prompts in the text encoding. We have opted to integrate the HiDream-I1 FULL inside a node-based generative AI interface called ComfyUI. It allows for complete control over the entire T2I inference pipeline, from model checkpoints, variational autoencoders, text encoders, samplers and optional additional detailers and upscalers. HiDream’s sparse diffusion transformer architecture, multi-encoder semantic processing and optional distillation techniques,

combined with complete control over the entire node-based pipeline inside ComfyUI [15] allows us to leverage its capabilities in diverse applications, as is represented in Figure 1.
During the trial phase, we input various combinations of selected words into the program and experimented with variations and word order combinations. As a starting point, we used the input phrase: two-piece pyjamas, long-sleeved top, long pants with an elastic waistband, sleepwear for women, loose cut design and material for autumn/winter season. Based on the survey results, we defined ten input prompts that served as the foundation for generating AI-driven sleepwear designs. Subsequently, we added the following variations to the initial phrase:
- Prompt 1: round neckline, one-piece sleeves without rib knit wristband, no prints on the top and pants, long pants without rib knit hem, light blue colour, made of cotton material.
- Prompt 2: V-neckline, raglan sleeves with rib knit wristband, no prints, long pants with rib knit hem and without drawstrings in the waistband, blue colour, cotton material.
- Prompt 3: round neckline, set-in one-piece sleeves or raglan sleeves with rib knit wristband, long pants with rib knit hem and without drawstrings in the waistband, no prints, made of cotton terry cloth material.
- Prompt 4: round neckline with polo slit and buttons, set-in one-piece sleeves, long pants with rib knit hem and drawstrings in the waistband, pastel rosa colour, small heart prints in contrasting colour, made of cotton material.
- Prompt 5: top with gathered scoop neckline, one-piece sleeves or raglan sleeves, long pants with an elastic waistband and without drawstrings in the waistband, beige or nature colour, small printed motifs on the fabric, made of cotton material.
- Prompt 6: light grey coloured long-sleeved top with keyhole neckline, the top fabric features small black star prints, black coloured long pants with rib knit hem, made of bamboo material.
- Prompt 7: long-sleeved light blue coloured top with round neckline and raglan sleeves, the top fabric features small dot motifs/prints in contrasting colour, long pants are in dark blue colour, made of cotton material.
- Prompt 8: long-sleeved shirt with collar, front part with placket with buttons and pocket, set-in one-piece sleeves without cuff, long pants without drawstrings in the waistband, white colour, made of silk material.
- Prompt 9: long-sleeved shirt with standing mandarin collar, front part with placket with buttons and pocket, set-in one-piece sleeves without cuff, long pants without drawstrings in the waistband, mint pastel colour, made of silk material.
- Prompt 10: long-sleeved shirt with collar, front part with placket with buttons and pocket, set-in one-piece sleeves without cuff, long pants without drawstrings in the waistband, violet colour, small printed motifs on the fabric, made of satin material.
All prompts left the pose data open, allowing the generative model to generate a random unique pose. The pose itself could be additionally controlled either by describing it in the text prompt or using additional neural network structures like ControlNet [16], which adds spatial conditioning controls to a text-to-image diffusion model.

3. RESULTS WITH DISCUSSION

3.1. An analysis of survey results

As sleepwear and textiles can vary by seasons, our first question focused on whether consumers wear sleepwear during summer and winter. Of the 432 responses, 72 % of respondents stated that they wear sleepwear in the summer, while 84 % wear sleepwear in the winter. Due to the variety of sleepwear styles a1 seasons, we focused only on sleepwear worn during the autumn/winter in the following. In winter, consumers primarily wear two-piece sleepwear, such as pyjamas (set of shirt/top and pants), or a combination of a long-sleeved top with long pants or leggings. It has also been established that the majority of the respondents like small prints e.g. dots, hearts, teddy bears, etc. (46 % of respondents) and flower prints or motifs from nature (31 %). The results also show that about 30 % of respondents do not like patterns and prints at all and 68 % of the respondents do not like details nor the accessories that seem insignificant to them (e.g. buttons, pockets, flounces, ruffles, zippers etc.). About 31 % of the respondents do not mind anything on their sleepwear, while 37 % are bothered by buttons, 36 % by zippers, and 20 % by strings and ribbons. It was also found that 22 % of the respondents like lace details, 17 % like pockets, 10 % like trims (e.g. satin), and 10 % like strings and ribbons. Consumers wear primarily blue sleepwear, followed by grey, black, white and beige sleepwear. It was also found that the respondents primarily like light shades, followed by pastel and dark shades. In winter, the respondents often wear cotton, and also flannel and terrycloth sleepwear, but less often silk, satin, modal and lace sleepwear [9].

3.2. An analysis of AI-driven sleepwear designs

Figure 2 presents the results of AI-generated two-piece women’s pyjamas made of light blue cotton material for the autumn/winter season. The loose-cut pyjamas consist of a long-sleeved top and long pants with an elastic waistband. From the generated pyjamas shown in Figure 2, only minor differences among the models can be observed, such as variations in the pyjamas’ colour (which was defined as light blue), the colour of the drawstrings in the waistband (either white or light blue), and the presence of pockets on the pants, a feature not specified as an input parameter in the prompt. All pyjama tops feature a round neckline and set-in one-piece sleeves with rib knit wristbands, which were defined as negative parameter. However, a few examples include raglan sleeves, which were not specified in the input prompt. The pants are mostly loose-cut with a consistent design, all including drawstrings in the waistband. It is also notable that none of the pants feature rib knit hems, as this was defined as a negative parameter. Since the round neckline was not explicitly specified, it is unsurprising that necklines do not display contrasting piping.

Figure 2: AI-generated pyjamas created using Prompt 1

Figure 3: AI-generated pyjamas created using Prompt 2

AI-generated blue-coloured loose-cut women's pyjamas, made of cotton material for the autumn/winter season, are shown in Figure 3. The two-piece pyjamas consist of a long-sleeved top and long pants with an elastic waistband. From the results shown in Figure 3, only minor differences among the models can be observed, such as slight variations in the pyjamas' colour (defined as blue), and the presence of pockets on the pants - a feature not specified as an input parameter in the prompt. In the input prompt, the pants were defined as having an elastic waistband without drawstrings, and with a rib knit hem. However, as seen in Figure 3, most pants lack rib knit hems, and all include drawstrings in the waistband - despite this being specified as a negative parameter. All pyjama tops feature a V-neckline and raglan sleeves with rib knit wristbands, with only one example including a V-neckline with a slit and buttons (e.g., Figure 3c).

Figure 4: AI-generated pyjamas created using Prompt 3

Figure 4 presents the AI-generated results of mint-coloured two-piece women's pyjamas made from cotton terry cloth material, intended for the winter season. The loose-cut pyjamas consist of a long-sleeved top and long pants with an elastic waistband. From the pyjama designs shown in Figure 4, only minor differences among the models are observable. Most pants have rib knit hems, and all pants include drawstrings in the waistband, which was specified as a negative parameter. Interestingly, all pants also have pockets, although this feature was neither specified as an input nor as a negative parameter. All pyjama tops feature a round neckline and raglan or set-in one-piece sleeves with rib knit wristbands. The pyjamas share a consistent light mint colour, as defined in the prompt. In this research, we were interested in whether there were noticeable differences among the defined materials. In Prompts 1, 2, 4, 5, and 7, the material was defined as cotton; in Prompt 3, as cotton terry cloth; in Prompt 6, as bamboo; in Prompts 8 and 9, as silk; and in Prompt 10, as satin. However, we did not specify whether the fabric was jersey knit or another type of knit or textile. Comparing the generated pyjama models in Figures 2, 3, and 4, we observe slight differences in the appearance of the material. In Prompt 3, the material was defined as cotton terry cloth, whereas in Prompts 1 and 2, it was simply defined as cotton, all specified for the autumn/winter season. Terry cloth is recognizable by its looped pile on one or both sides, creating a soft, plush texture that gives the fabric a somewhat bulky and absorbent appearance. It often looks thick and cozy, with a matte finish rather than a sheen. As observed in Figure 4, the pyjamas made from terry cloth material appear soft, bulky, and thick, with a visibly plush texture. We were surprised to find that the difference between cotton and terry cloth materials, as defined, was noticeable in the generated designs.

The results of AI-generated pastel rosa-coloured women's pyjamas, made of cotton material with small heart prints in a contrasting colour, are presented in Figure 5. The loose-cut pyjamas consist of a long-sleeved top and long pants with an elastic waistband. From Figure 5, only minor differences among the pyjama models can be observed. Most tops feature a round neckline with a polo slit and buttons, along with set-in one-piece sleeves and rib knit wristbands. However, a few tops display a front placket with buttons (e.g., Figure 5g), despite this detail not being defined in the input prompt. Variations in the length

of the polo slit and the number of buttons is also apparent, likely due to the absence of specific instructions regarding these elements. Notably, in Figure 5a, the upper button and buttonhole are misaligned. In some cases, the buttons on the pyjama tops differ in shape or colour, despite no such variation being specified in the input phrase. All pants feature drawstrings in the waistband, while rib knit hems appear on only some models. Interestingly, all pants are designed with pockets, even though this feature was neither specified as an input nor as a negative parameter. The input phrase specified that the pyjama fabric should contain small heart prints in a contrasting colour. As expected, the resulting patterns appear generic and lack a distinctive design identity. This is likely due to insufficient detail in the prompt regarding the specific visual characteristics of the textile pattern. Although the motif was described as small, the heart prints vary slightly in size, colour (e.g., white, dark rosa, grey), and density. When testing the input phrases, we found that specifying the size of the print motifs (e.g., 1 cm) did not produce heart prints at the intended scale. We also tested a negative phrase (e.g., "heart motifs filled with colour"), but the generated pyjamas still did not feature contoured (i.e., unfilled) heart shapes, as expected. These findings suggest that a custom textile pattern proposal may be necessary to achieve more accurate and visually refined print designs.

Figure 5: AI-generated pyjamas created using Prompt 4

AI-generated beige or natural-coloured loose-cut women’s pyjamas, made of cotton material for the autumn/winter season and featuring small motifs or prints, are presented in Figures 6 and 7. The two-piece pyjamas consist of a long-sleeved top with a gathered scoop neckline and long pants with an elastic waistband. From Figure 6, it can be observed that most pants follow a similarly loose-cut design with elastic waistbands and drawstrings, although drawstrings were specified as a negative parameter. Some pants are again designed with pockets, even though this feature was neither specified as an input nor as a negative parameter. The majority of tops display a gathered scoop neckline and raglan sleeves, as shown in Figure 6. However, some designs include additional elements such as slits, buttons, or drawstrings at the neckline (Figure 7), as well as sleeves finished with either gathered (Figure 6f) or ribbed wristbands (Figure 7a) - features not specified in the input prompt. We also observed that gathers and slits appeared inconsistently in the neckline of some tops, as presented in Figure 7. Since the motif for the print was not defined

in terms of colour, shape, or placement, the generated motifs appear visually appropriate for the overall pyjama design. Although the motifs are not rendered with high precision, discernible elements include small floral, nature-inspired, and other ornamental forms. The colours of the pyjamas are predominantly beige, with motifs in brown or light brown tones, contributing to a cohesive visual impression.

Figure 6: AI-generated pyjamas created using Prompt 5

Figures 8 and 9 present the results of AI-generated designs for loose-cut women's pyjamas featuring small star and dot prints. The two-piece pyjamas shown in Figure 8 are made from bamboo fabric and consist of a light grey, long-sleeved top with small black star prints and a keyhole neckline. They are paired with black long pants. As seen in Figure 8, minor variations exist among the pyjama models. The pants are generally loose-cut, some feature white star motifs and pockets, and others differ in hem design, lacking rib-knit finishes. This suggests that certain input parameters were not consistently followed. The keyhole neckline also varies among the models. In all cases, it features grey piping; however, its shape and detailing differ - appearing as a teardrop, incorporating a string, or rendered as a simple slit - none of which were specified in the original input phrase. As we can see from Figure 8, the star motifs on the tops are approximately the same size, but the pattern density varies slightly. We also observed that the textiles lacked the characteristic subtle sheen. Bamboo jersey is generally known to have a silk-like sheen and falls more softly than cotton. However, in Figure 8, this shine is not apparent, as the material appears more similar to cotton. In our previous research using the Stable Diffusion model, we observed subtle differences between cotton and bamboo materials [11].

Figure 7: AI-generated pyjamas created using Prompt 5, illustrating deviations from the input parameters and inaccuracies in design details

Figure 8: AI-generated pyjamas created using Prompt 6

The pyjamas made from cotton material, shown in Figure 9, include a light blue long-sleeved top, paired with dark blue long pants. The fabric of the top features small dot motifs in a contrasting colour. From Figure 9, it can be observed that most pants follow a similar loose-cut design, featuring an elastic waistband. Interestingly, most pants also include pockets and drawstrings in the waistband in varying colours (e.g., white or blue), even though these features were not specified as either input or negative parameters. Some pants also feature dot motifs, even though this was specified as a negative parameter. All tops feature a round neckline and raglan sleeves, along with rib-knit wristbands - a detail that

was not specified as an input or negative parameter. A few tops feature round necklines with contrasting piping (e.g., Figure 9g), although this feature was not explicitly specified, whereas others display round necklines with light blue piping. Additionally, the small polka dot pattern varies slightly in density, dot size, colour (e.g., dark blue, white, grey, rosa, etc.), and composition. Although the input prompt did not precisely specify the small dot pattern, a greater degree of diversity and variation in the resulting designs was expected.

Figure 9: AI-generated pyjamas created using Prompt 7

Figures 10 and 11 present AI-generated two-piece loose-cut women's pyjamas made of silk, designed for the autumn/winter season. Among the white pyjama designs shown in Figure 10, minor differences can be observed between the models. All pants follow a similar loose-cut design with an elastic waistband. Notably, most pants include pockets - a feature that also appears on some shirts (e.g., Figures 10c and 10f) - despite not being specified as either an input or a negative design parameter. The shirts share a similar design, featuring a front placket with white buttons, a notched collar (rever), and a rectangular chest pocket - this detail was not specified in the input prompt. The hems of the shirts are either straight or slightly shaped, with minor variations in length. Some set-in sleeves are finished with loose-cut cuffs, another element not specified in the design prompt. From Figure 10, the distinct sheen of the material is noticeable, consistent with the specification that the pyjamas are made of silk. Silk textiles are known for their exceptional sheen, which results from their smooth surface that reflects light, giving them a luxurious and radiant appearance.

The mint pastel pyjamas shown in Figure 11 feature a long-sleeved shirt with a stand-up mandarin collar and loose-cut, full-length pants with an elastic waistband. The mandarin collars are characterized by their rounded edges, consistent with the typical design of this collar style. The shirts fasten with a button placket and include a chest pocket - either on the right or left side - although this detail was not specified in the input. The hems of the shirts are either straight or slightly shaped, with minor variations in length. In some designs, an additional button is visible at the collar (e.g., Figure 11f). Certain set-in sleeves are finished with loose-cut cuffs (e.g., Figures 11a and 11f), a feature also not specified in the original prompt. Most pants again include pockets, which are likewise present on some shirts (e.g., Figures 11b and 11c), despite this detail not being indicated in the input

parameters. As observed in Figure 11, the distinctive sheen of the material is also evident, aligning with the specification that the pyjamas are made of silk.

Figure 10: AI-generated pyjamas created using Prompt 8

Figure 11: AI-generated pyjamas created using Prompt 9

Figure 12 displays the results of AI-generated loose-cut women’s pyjamas made of light violet satin material with small prints. This two-piece set comprises a long-sleeved shirt featuring a collar, front button placket, and a chest pocket, paired with long pants that have an elastic waistband. The pyjama models in Figure 12 closely resemble those shown in Figure 10, differing primarily in colour and print. Since the print motif was not defined in terms of colour or shape, the generated designs appear visually harmonious with the pyjamas’ colour. Although the motifs are not clearly visible, certain small floral and other ornamental elements remain recognizable. As observed in Figure 12 (e.g., Figure 12f), a subtle sheen characteristic of satin is noticeable on some pyjamas, reflecting the fabric’s smooth and lustrous surface; however, on most pyjamas, the sheen is not apparent, and the fabric resembles cotton in appearance.

Figure 12: AI-generated pyjamas created using Prompt 10

4. CONCLUSION

This study explores the application of generative AI in women's sleepwear design, drawing on survey data to capture consumer perceptions and preferences. Through an analysis of AI-generated pyjama models, it offers insights into the potential of generative models to support the creative process in fashion design, while also identifying their current limitations.

Overall, the AI generally adhered to fundamental design parameters such as garment type, silhouette, and fabric colour - successfully producing loose-cut, two-piece pyjamas with long-sleeved tops and elastic-waistband pants. However, minor deviations emerged in certain design features, such as the inclusion of pockets and drawstrings, even when these elements were either unspecified or explicitly excluded. This indicates an inconsistency in the model's ability to interpret negative input parameters. Similarly, sleeve finishes (particularly knit finishes and cuffs), pant hem details (e.g., knit finishes), and neckline styles occasionally strayed from prompt specifications, suggesting either interpretive bias on the model's part or insufficient clarity in the instructions. These deviations highlight the challenges of relying solely on prompt-based instructions to accurately capture detailed garment construction features, as vague or incomplete prompts can lead to misinterpretations. Consequently, achieving greater accuracy in generated apparel designs may require more explicit and detailed input specifications or the integration of custom pattern and construction elements. Such approaches could help ensure that both visual and structural features are accurately represented in the final outputs.

Material differentiation was partially successful. Cotton terry pyjamas exhibited the expected plush and voluminous texture, clearly distinguishing them from those made of standard cotton. Silk - and in some cases, satin - pyjamas generally reflected their characteristic sheen. In contrast, bamboo knitwear did not exhibit its typical silky softness and sheen, appearing more similar to cotton. These results show that while AI can represent some textile properties effectively, it struggles with subtler or less familiar materials. The generation of printed motifs (e.g., polka dots, stars, hearts) revealed limitations in prompt-based control over pattern precision and identity. Outputs tended to appear generic, with

variations in size, colour, and composition - particularly when prompts were vaguely defined (e.g., small prints). This suggests that achieving high-fidelity textile prints may require the integration of custom textile pattern inputs, rather than relying on descriptive prompts alone.

In summary, generative AI shows promising potential as a creative tool in fashion design, capable of producing visually compelling garments. Nonetheless, the inconsistencies observed - particularly in material depiction, motif precision, and detailed construction elements - highlight the need for improved prompt engineering and model refinement. Future research should focus on increasing input specificity and exploring hybrid workflows that combine AI generation with human oversight to enhance design precision, material realism, and overall output quality.

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DEVELOPMENT OF FORM AS A FORMATIVE ELEMENT IN THE INDUSTRIAL FASHION PRODUCT

Professional paper
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ABSTRACT: *The main function of design is to shape usable objects from various fields. Design emerged with the advent of the industrial revolution and the serial, automated, mass production of various goods for an unknown consumer. Design seeks to anticipate the tastes and needs of individual categories of buyers. The design must be attractive and meet the taste of the consumers for whom it is intended. Although, it is often equated with style, design, in addition to the simple shape of the product, must meet additional criteria. First of all, these are: functionality, technical quality, attractiveness, reliability and the creation of a relationship of trust between the product and the consumer. Good design is actually a combination of a classical attitude, similar to that of the Renaissance, which is combined with today's technology, which would create what the world did not know was missing at that time of the Renaissance period. The task of good design is to create a used object, which will achieve a certain progress in relation to the already common stereotypes and thus will enable economically more profitable production, i.e. will bring greater profit. With the advent of the first sewing machine in the 19th century, the mass production of clothing, namely Ready to wear clothing, came, which means that the clothing is already sewn in different ready-made sizes and shapes, so that it can be worn immediately without additional adjustments. With the constant change of styles in art and literature, fashion has changed throughout history, from Romanticism to the present day.*

Keywords: *Industrial design, Fashion, Clothing, Form, Industrial Aesthetic Product.*

RAZVOJ FORME KAO FORMATIVNOG ELEMENTA U INDUSTRIJSKOM MODNOM PROIZVODU

APSTRAKT: *Glavna funkcija dizajna je oblikovanje upotrebnih predmeta iz različitih oblasti. Dizajn se pojavio sa pojavom industrijske revolucije i serijske, automatizovane, masovne proizvodnje raznih dobara za nepoznatog potrošača. Dizajn teži da predvidi ukuse i potrebe pojedinih kategorija kupaca. Dizajn mora biti atraktivan i zadovoljiti ukus potrošača kojima je namenjen. Iako se često poistovećuje sa stilom, dizajn, pored jednostavnog oblika proizvoda, mora da ispunjava dodatne kriterijume. Pre svega, to su: funkcionalnost, tehnički kvalitet, atraktivnost, pouzdanost i stvaranje odnosa poverenja između proizvoda i potrošača. Dobar dizajn je zapravo kombinacija klasičnog stava, sličnog onom iz renesanse, koji je kombinovan sa današnjom tehnologijom, što bi stvorilo ono što svet nije znao da nedostaje u to vreme renesansnog perioda. Zadatak dobrog dizajna je da stvori upotrebljiv predmet, koji će postići određeni napredak u odnosu na već uobičajene stereotipe i time omogućiti ekonomski profitabilniju proizvodnju, odnosno doneti veći profit. Pojavom prve mašine za šivenje u 19. veku došla je masovna proizvodnja odeće, naime odeće „Ready to wear“, što znači da je odeća već sašivena u različitim gotovim veličinama i oblicima, tako da se može odmah nositi bez dodatnih podešavanja. Uz stalnu promenu stilova u umetnosti i književnosti, moda se menjala kroz istoriju, od romantizma do danas.*

Ključne reči: *Industrijski dizajn, moda, odeća, oblik, industrijski estetski proizvod.*

1. INTRODUCTION

The main function of design is to shape usable objects from various fields. Design emerged with the advent of the industrial revolution and the serial, automated, mass production of various goods for an unknown consumer. Design seeks to anticipate the tastes and needs of individual categories of buyers.

The design must be attractive and meet the taste of the consumers for whom it is intended. Although, it is often equated with style, design, in addition to the simple shape of the product, must meet additional criteria. First of all, these are: functionality, technical quality, attractiveness, reliability and the creation of a relationship of trust between the product and the consumer.

Contemporary design tries to respond to the demand for formal novelties, which come from the audience, which is constantly "bored" in a society of spectacles, of enjoyment, a society of consumption and communication. When it comes to industrial design in fashion, even the word fashion itself, from the Latin modus, which means way, rule, rhythm, time, is a term that denotes popular styles and trends, in various spheres of human activities and thinking related to a certain moment in time [1].

Fashion is a means of identification and socialization, for symbolic communication and expression of hedonism. Fashion as a dynamic act of short duration and it can be placed in the context of transforming the established frameworks, of life and society. Fashion is an interdisciplinary category, inspired by the characteristics of different branches: [2] From art history, sociology, psychology and philosophy, to ethnology, anthropology and

semiology, i.e. the science of signs and their meaning. Fashion is a system of signs that interact with the human body, at a particular time and in a particular space. Fashion is a means of identification, socialization, and symbolic communication. The terms "modern" and "unmodern" are indicators of the conformity of something, together with the current requirements of modern expression [3, 4].

Industrial design is primarily an aesthetic category, and therefore it must not be exclusively or to a large extent, determined by the technical and functional properties of the product. Industrial design represents that aspect of the product that makes the product itself aesthetically valuable, attractive and acceptable to the buyer. Good design creates unity, functionality, economy and expediency, in certain living conditions.

Good design is actually a combination of a classical attitude, similar to that of the Renaissance, which is combined with today's technology, which would create what the world did not know was missing at that time of the Renaissance period

The task of good design is to create a used object, which will achieve a certain progress in relation to the already common stereotypes and thus will enable economically more profitable production, i.e. will bring greater profit [5].

2. AVANT- GARDE OF THE INDUSTRIAL AGE IN FASHION

With the advent of the first sewing machine in the 19th century, the mass production of clothing, namely Ready to wear clothing, came, which means that the clothing is already sewn in different ready-made sizes and shapes, so that it can be worn immediately without additional adjustments. With the constant change of styles in art and literature, fashion has changed throughout history, from Romanticism to the present day. The main characteristic of Romanticism in women's clothing is the appearance of the voluminous, voluminous dress called the Crinoline dress. The construction under the skirt was made of horsehair, linen and cotton, so that it would not be too heavy to wear. The construction consisted of: Large round rings, arranged in size from smallest to largest, and they were connected by transverse straps. These rings created the appropriate shape, with the possibility of the dress being able to fall down, i.e. fall as beautifully as possible and spread towards the floor. These constructive circles are the best illustration of the fact that geometricism in the overall design is especially present in the ranks of fashion. In addition to the crinoline, another main characteristic of clothing during that period was the corset. It gave the female body the recognizable so-called X figure.

In Romanticism, there was a tendency to overload form and decoration, which was achieved with floral applications, circles and lace. Another turning point in that period was the appearance of underwear, which until then had been worn only by selected women, while in the mid-19th century, it was imposed as a necessity, due to the crinoline dress.

Figure 1: Large round rings Arranged by size, from smallest to largest
The rings are connected by 1bars

In the era of Queen Victoria (1837-1901) the class difference is evident, where Factory-made, i.e. factory-made suits were intended for the lower classes, while Made to measure suits were intended for the upper classes. In 1892, the first issue of the fashion magazine VOGUE was published. The founder of the magazine VOGUE, Arthur Baldwin Turner, had the idea of creating a social magazine, intended for the elite in New York.
In 1851, the first sewing machine, Singer, was invented. Since 1856, the crinoline as the most striking women's clothing, has changed a lot. Crinoline dresses were made of steel, then semi-crinolines were made, until 1868, when this type of designed dress completely disappeared. Since then, volume has been achieved with fabrics, and the emphasis has been placed on a narrower and more slender silhouette. In the early 20th century, during the Secession, i.e. the economic crisis, and the time of the artistic movements Art Nouveau, Fauvism and Cubism, the ideal silhouette of a woman was already completely different from that of the Victorian era [6].
Now the ideal silhouette was considered the so-called S-silhouette, i.e. an emphasized chest and back. The lower silhouette was much simplified, while the emphasis was placed on the wrists, which were enriched with head decorations and ribbons of stuffed swallows and sparrows. Women began to wear skirts - trousers for cycling, as well as hats with scarves and glasses for driving a car [7].The most important designer at that time was Paul Poiret. Influenced by Orientalism, Poiret in 1905 took the Kimono as a model for designing a collection. In clothes created for the upper classes, he freed women from the corset, while focusing on details and handcraft. Poiret especially popularized Orientalism with his collection called "A Thousand and One Nights".

2.1. Variations of Fashion Product Development

In that way, Poiret contributed to designing the recognizable skirt for women, the so-called Hobble skirt - a narrow skirt, or a skirt in the shape of a bar, as well as designing the Kimono coat, and also introducing large, i.e. long gloves and turbans for the head. The Hobble skirt is a stylized skirt, which was so narrow in the thighs that it hindered women's walking. Hobble skirts were a short-lived fashion trend, which reached its peak between 1908 and 1914. Poiret presented his collections on the streets of cities, with his twenty models [8].

Figure 2: Clothing in the Victorian Era - Poiret contributed to designing the recognizable skirt for women, the so-called Hobble skirt - a narrow skirt or a skirt in the shape of a bar, as well as designing the Kimono coat, and also introducing large, i.e. long gloves and turbans for the head.

Figure 3: The iconic cape, created by Paul Poiret in 1905

Figure 4: Hobble skirt – A stylized skirt that was very tight in the thighs. It even hindered women from walking.

Figure 5: Long pencil skirt - A long, narrow, pencil-shaped skirt, considered a modern variation of the old-fashioned Hobble skirt.

2.2. Fashion Product Development through artistic movements

From 1910 to 1920, various artistic movements were active: Cubism, Futurism, Dadaism, Constructivism and Abstraction. But for the development of fashion in that period, of course, the most significant was the appearance of the fashion designer Coco Chanel.

Coco Chanel first appeared as a fashion designer of headwear. The hats she presented herself with seemed much simpler than those created earlier. In 1918, she opened her first

fashion studio in Paris. From 1910 to 1920, various artistic movements were active: Cubism, Futurism, Dadaism, Constructivism and Abstraction. Then, Chanel began to create simpler forms of clothing, following the example of men's clothing, and so on the basis of the men's shirt, she created the women's dress [9, 10].

In 1953, she presented her first collection, in which she introduced her first classical costume (a skirt and sweater) and launched it on the European market. She also designed costumes for the Russian Ballet with the Russian composer Igor Stravinsky, from which sportswear later developed. In 1920, Chanel broke into the American market, with the so-called "Flapper" girl. Flapper girls were a "new breed" of young women in Western Europe and America in the 1920s who showed their contempt for what was then considered acceptable behavior. Women became freer, more aggressive, and refused to be confined to the domestic sphere. The main characteristics of the so-called "Flapper" girl are: A skirt with a length of 3 cm below the knee, short hair, and wearing looser clothing. Modern clothing was lighter and more flexible, better suited to a modern woman like the flopper - the girl who also wanted to play sports. In her dressing, the woman was no longer limited to slim waists and long skirts, but the modern woman of the 1920s had now become an independent and free thinker, no longer following the established rules.

Figure 6: Flapper ski

One of Coco Chanel's most significant achievements is definitely the design of the "Little Black Dress". It is a sleeveless dress, with a length just above the knee, which gives a woman the opportunity, with little jewelry, to wear the dress on various occasions. Many designers later experimented with redesigning this dress and adding additional decorations. Among them: Christian Dior, Balenciaga, Givenchy and many others.

Figure 7: Actress Audrey Hepburn in a black dress created by Coco Chanel

During World War II, ready-to-wear clothing was of great importance. Efforts were made to express creativity through construction, rather than through expensive materials. In Paris, women continued to cultivate high fashion, wearing shoes made of metal, wire, wood, and cork. In England, women wore simpler clothing out of solidarity with the soldiers. Women in England also wore a three-piece suit: They wore a skirt with a straight silhouette, with a length just below the knee, then a shirt and jacket, emphasized by shoulder pads, made of simple inexpensive materials. Pin-up girls were popular in America, because they raised the morale of soldiers on the battlefield [11].

Christian Dior, as one of the greatest fashion designers of all time, first worked as a fashion illustrator for Vogue magazine, and then in 1946 opened his own fashion house "Dior". He presented his first collection called "New Look" in 1947. In this collection, he returned the attributes of a woman: rounded and lowered shoulders, and an upper garment that resembled a corset. He emphasizes the higher waist, the wide pleated skirt, the hips are emphasized with inserts, and as inevitable details he takes gloves, an umbrella and a black hat. The aforementioned Dior collection "New Look" caused protests in America called "Anti New Look". People took to the streets, outraged because Dior's silhouette did not suit either Parisian or American women. But Dior ignored this, preserving the existing look.

Figure 8: Creation by Christian Dior

2.3. Fashion Product Development through the influence of the Hollywood film industry

In the 1950s and 1960s, Hollywood film stars promoted a so-called anti-fashion, especially among men. Legendary actors Marlon Brando and James Dean popularized clothing that was then reserved exclusively for workers or naval officers. The white T-shirt, blue jeans, and black leather jacket became a uniform that expressed a certain attitude of dissatisfaction and reflected the vanity of the individual.

For women, the focus was on designing handbags and hats, promoted by actresses of the time. The youngest designer in the world, Yves Saint Laurent, then only 17 years old, became Dior's personal assistant and created eight fashion collections for him.

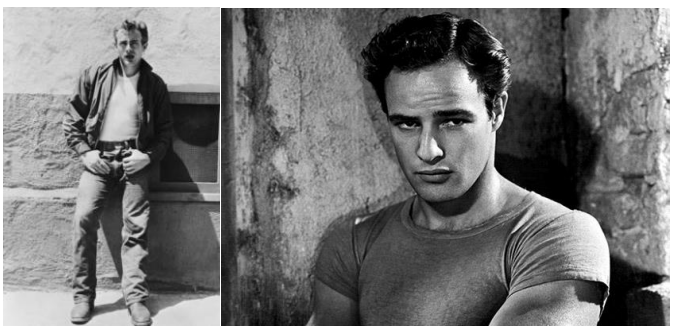

Figure 9: James Dean and Marlon Brando as the embodiment of the fact that the white or black T-shirt, blue jeans and black leather jacket became a uniform that expressed a certain attitude of dissatisfaction and reflected the vanity of the person.

After Dior's death, the young designer, Yves Saint Laurent became the head designer of the Dior fashion house and worked on his first collection called "Trapeze". He experimented with corsetry at the waist, left the shoulders natural, and emphasized the trapezoid shape, more precisely the A-line reaching below the knee. He also left the gloves, still present. In 1966, Dior created a pop art collection inspired by the painter Andy Warhol. In the mid-1960s, designers introduced new unusual materials to create clothes.

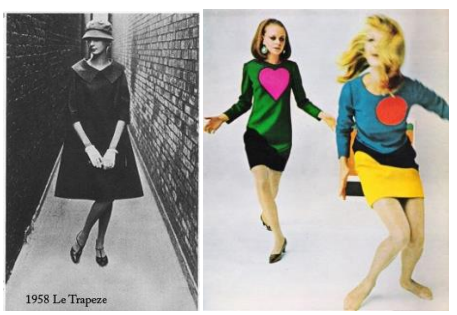

Figure 10: Creations by Yves Saint Laurent

Mary Quant is the first designer to use PVC material for the production of coats and boots. In America, clothing called "Paper clothing" appears. An example of this type of clothingis the so-called "Souper Dress" - a dress based on Andy Warhol's painting called "Campbell Soup Cans" - "Campbell Soup Cans" - i.e. soup cans from the Campbell company.

2.4. Fashion Product Development through the Music industry

Then tights of various shapes and colors appear. In 1964, the French fashion designer André Courrèges - André Courrèges created a suggestion of a space look, and thus created a collection that in some way interrupted the conventionality and tradition in fashion. The models were dressed in flat white boots, white or silver pants. He created a collection in which miniskirts appeared for the first time at a haute couture show. They were flat and comfortable skirts, made according to the principles of the Bauhaus design house.
In the seventies, Disco fashion appeared, a period in which traditional clothing was no longer worn. Synthetic materials were used, bright and even very bright colors, shiny elements, short pants, shorts, blouses, etc. were used. It was promoted by actors and singers. Some of the most famous are David Bowie, Gary Glitter and John Travolta, in their music videos and films.

Figure 11: This photo shows the use of synthetic materials, which use bright, even very bright colors, shiny elements, short pants, shorts, blouses, etc. David Bowie, Gary Glitter, and John Travolta are featured in their music videos and films.

2.5. Fashion Product Development through geometric shapes in fashion design

Geometry in fashion appears from the patterns of clothing to the tailored pieces themselves. Geometry does not always have to be noticeable. It can be hidden with cuts that, when sewn together, somehow reduce the visual impression of a geometric shape. Regular geometric motifs are one of the oldest motifs that adorned clothing and jewelry. The expansion and development of geometric motifs in art and fashion appeared after the First World War, with artistic movements such as Cubism and Suprematism as part of Abstract Art.
In the textile industry, the tendency towards geometric motifs is most noticeable in the works of members of the Bauhaus school. Geometric shapes as applications in textile

patterns are very popular even today. One of the most famous collections that have a geometric basis is definitely the collection of Yves Saint Laurent.
It is the minimalist collection, designed after the example of the paintings of Piet Mondrian. Yves Saint Laurent, in his Fall/Winter 1965-66 collection, presented several white dresses, with a simple so-called "A" cut, i.e. a cut in the shape of the letter A. It is a sleeveless cut, and on these dresses he shows several versions of Mondrian's works. On the dresses there are black straight lines, which divide the dress into several parts.

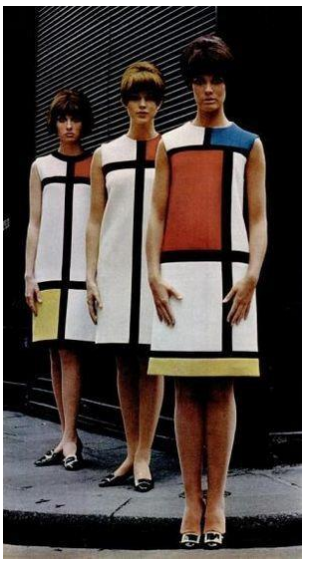

Figure 12: Yves Saint Laurent's creations, inspired by Piet Mondrian's paintings In this picture we see a dress from the front. It has seven parts Of them, three parts are in different colors (red, yellow, blue) The rest of the dress is white The second dress is in four parts in which only one part is red. The last dress is in six parts, one is yellow, the other is red, and the rest are white.

Another designer who wanted to "play" with geometry in some way is the aforementioned André Courrèges. He often used lines in his collections as the basis of the clothes. The skirts were often geometric in shape, while one of his most interesting dresses was a dress with side slits in the form of stacked circles. Sonia Delaunay was an artist and fashion designer who worked in the art direction called Orphism. Her designs are emphatically colorful, full of colors and geometric shapes [12, 13].

Figure 13: In this image we see only some parts of Sonia Delaunay's textile patterns

Andre Courreges, the innovative French fashion designer whose creations spoke of the future, symbolised stylistic freedom and provoked hot dispute over whether he was first with the miniskirt, has died at his home outside Paris. He was 92. According to the Courreges firm, he had suffered from Parkinson's disease for 30 years. One of the most influential couturiers of his time, Courreges won fame for fitting out his models in attire that seemed to suggest not past eras or conventions, but the space age [14].

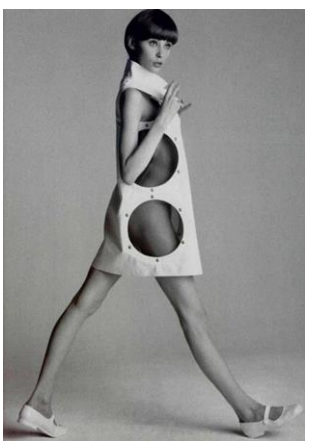

Figure 14: Geometric creation by André Courrèges. She used lines as the basis of the clothing. The skirts had a predominantly geometric shape. One of her most interesting dresses was a dress with side slits, in the form of stacked circles.

Figure 15: In this image we see how Sonia Delaunay has incorporated her pattern into her clothing. An umbrella with triangles on it, and the same motif extends to the dress and coat, while in the other woman we see a linear motif, which also runs through the entire garment.

Ichiro Suzuki is a Japanese designer who has used geometry to create optical illusions on clothing. Suzuki uses geometric shapes and perspective to achieve a sense of the third dimension [16].

Figure 16: In this image we see a men's jacket, with a cube pattern in isometric projection.

An example of how geometry is not only in patterns, but also in cuts, is the dress by designer Gareth Pugh. In addition to high fashion, geometry is quite common among high street brands. Some of the most famous are Zara and H & M.

Figure 17: In this image we see how some geometric bodies can be part of clothing, such as pyramids in this case.

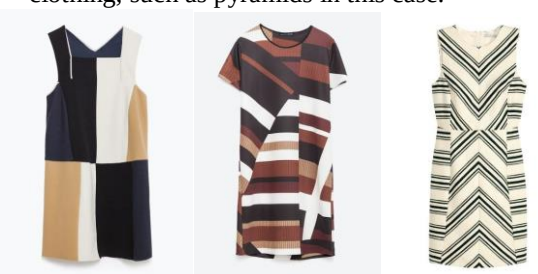

Figure 18: Zara dress Zara dress H & M dress

3. CONCLUSION

Design, which is a consequence of the industrial revolution, is created by the continuous dialectic, i.e. development, which unites technology, skill and society. In the constant development of industrial design, modernists have long defended the position of the differences between the avant-garde, i.e. contemporaries of new design, and kitsch. The avant-garde is considered a way of finding a direction for where it would be possible to continue the development of culture, in a contemporary cultural chaos, even transformed into a kind of cultural and ideological violence. But here the presence of kitsch, as a product of the industrial revolution, is inevitable. It denotes a set of distorted products that constitute mass culture. Because of these observations, classical industrial design, since the 1920s and 1930s, has attempted to use forms produced by the avant-garde.

In industrial design, functional aesthetics, i.e. simplified abstract form, gained a privileged position, giving rise to the so-called formal aesthetics. In that way, in the era of industrial design, there was a public condemnation of any figurative classical aesthetics, which resembled kitsch, although as we have said, kitsch is inevitable even in the era of the industrial revolution. The current evolution in industrial creativity stems from the need to facilitate the process of identifying and re-adapting the product

to today's increasingly complex society. Today, in the era of industrial design, functional objects are of particular importance, as although they are primarily functional, they are also carriers of a certain meaning, thus culturally integrating them into modern society.

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GOBELIN TAPESTRIES AND THEIR APPLICATION IN MODERN CLOTHES

Professional paper
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ABSTRACT: *Gobelin tapestry, as a form of handmade art, represents a significant part of the cultural and textile heritage, especially in the Balkans and the wider European region. This paper explores the transformation of gobelin tapestries as a decorative element in the home and their integration into contemporary fashion design. The research begins with the historical roots of* gobelin tapestry *its symbolic and aesthetic values, as well as the techniques used in their production. Special emphasis is placed on its role in the Macedonian tradition, where gobelin tapestry not only had a decorative function, but also symbolized female skill, patience and creativity, and mostly women's textile art, but men were no exception in the production of clothing, this textile art was rooted thousands of years ago in Macedonia, women first using woolen threads obtained from the goods they kept, then silk threads that they also produced themselves, and then imported and much more sophisticated needles and threads were used.*

The aim of the paper is to show how a traditional gobelin tapestry can be reinterpreted and adapted in the context of the modern fashion scene. Through the analysis of specific examples from domestic and international fashion designers who use tapestry motifs, textures and techniques in their collections, the creative potential of the old with the new is revealed.

The paper also explores in what ways contemporary clothing can preserve the authenticity of gobelin tapestry making by introducing innovations through new materials, technologies and approaches. The research is based on the analysis of visual materials.

The results show a growing interest in unique, handmade and culturally authentic pieces, especially in the context of sustainable fashion. Gobelin tapestry should not be seen only as a thing of the past artistic heritage, but as a source of inspiration and innovation in

design. Through its adaptation, it is possible to preserve cultural identity while developing a contemporary expression that values tradition.

Keywords: *Gobelin tapestry, traditional art, contemporary fashion, design, cultural heritage, textiles.*

GOBLENI I NJIHOVA PRIMENA U MODERNOJ ODEĆI

***APSTRAKT**: Goblen, kao oblik ručno rađene umetnosti, važan je deo kulturno-tekstilne baštine, posebno na Balkanu i u širem evropskom regionu. Ovaj rad naglašava transformaciju goblena kao ukrasnog elementa u kući i njihovoj integraciji u savremeni modni dizajn. Istraživanje počinje istorijskim korenima goblena, njegovih simboličnih i estetskih vrednosti, kao i tehnike koje se koriste u njihovoj proizvodnji. Poseban naglasak je na njegovoj ulozi u makedonskoj tradiciji, gde Goblen ne samo da ima samo dekorativnu funkciju, već je i simboliziralo ženske veštine, strpljenje i kreativnost i većinu tekstilnih umetnosti žena, ali izuzeci nisu ni muškarci u proizvodnji odeće, ova tekstilna umetnost bila je ukorenjena hiljadu godina u Makedoniji. Žene su prvo koristile vunene niti dobijene od robe koju su čuvale, zatim svilene niti koje su takođe same proizvodile, a zatim su se uvozile i koristile mnogo sofisticiranije igle i niti.*

Svrha rada je da se pokaže kako se tradicionalni gobleni mogu tumačiti i prilagoditi kontekstu moderne modne scene. Analiziranje specifičnih primera domaćih i međunarodnih modnih dizajnera pomoću goblenskih motiva, tekstura i tehnika u njihovim kolekcijama otkriva kreativni potencijal za staro sa novim.

Rad takođe istražuje na koji način modernu odeću može sačuvati autentičnost preko goblena, dizajna uvođenja inovacija kroz nove materijale, tehnologije i pristupe. Istraživanje se zasniva na analizi vizuelnih materijala.

Rezultati pokazuju sve veće interesovanje za jedinstvene, ručno rađene i kulturno autentične komade, posebno u kontekstu održive mode. Goblen ne bi trebalo da se vidi samo kao stvar prošlosti umetničkog nasleđa, već kao izvor inspiracije i inovacija dizajnera. Kroz njegovo prilagođavanje moguće je sačuvati kulturni identitet, dok razvijate modernu ekspresiju koja štiti tradiciju.

***Ključne reči**: goblen, tradicionalna umetnost, savremena moda, dizajn, kulturna baština, tekstil.*

1. INTRODUCTION

In the mid-15th century, Jean and Philibert Gobelins opened a fabric dyeing workshop on the outskirts of Paris. Their business quickly developed so well that in subsequent generations, members of this family decided to hire masters to produce gobelin tapestries. Their handmade paintings of wool and fine thread became very popular and so popular that in 1662, the French ruler Louis XIV decided to annex their workshop to the royal furniture factory.

When Jacob Wheeler started his bedding business in Berlin in 1893, he gave customers the opportunity to order the embroiderymotifs he advertised by mail order without having to visit the store. For that time, it was a very bold and unusual business move.
Interestingly, even then, Wheeler's customers, in addition to Germany, were also from our region.
Since 1907, the business has progressed so much that Jakob Wieler first printed a rich 72-page catalog in 1914.
During the bombing of World War II, Wieler's factory was completely destroyed, but fortunately the patterns for the tapestries were preserved, as they were kept in the owner's house.
Although the "Wieler Tapestry Company" has changed many owners since its founding, it still enjoys a great reputation and is loved throughout the world and in our region.
The palette of paintings by old masters was enormous with various motifs, portraits, scenes from the Bible, scenes from everyday life, traditional costumes from the country and the region
The most popular and expensive were Leonardo's Mona Lisa and The Last Supper, which still have their prestige to this day.

2. THE GOBELIN TAPESTRY AND ITS PRODUCTION

A mesh canvas is used to make the gobelin tapestry, and the stitch used is a specific diagonal stitch with wool, cotton or silk thread. The production requires enormous dedication, precision, patience and a sense of composition and color. Nowadays, there are also machine-made gobelin tapestries, but of course, handmade ones remain much more valuable. In many cultures, but also here in the Balkans, the gobelin tapestry has great symbolic meaning. In the past, it was often made as part of the b ride's dowry. With gobelin tapestries, the artist, that is, the person who makes the gobelin tapestry, has the freedom to express his creativity and thereby create a work of art that is unrepeatable and unique. What we are sure of, and without which this masterpiece cannot be created, are canvas, thread, needle and scissors.

Figure 1: Thread [7]

Figure 2: Embroidery accessories (scissors, tweezers, thimble, cotton, thread) [8]

For the beauty of the gobelin tapestry is crucial to the canvas that must be specified for embroidery. The choice of embroidered materials is really great. The most used cotton fabrics of varying weaving density, are depending on the embroidery and how thick the embroidery itself is (Golleti Willer Factory).

When choosing the fabric it is really important that it does not stretch, it contains a stretch or lycra. If the fabric is stretched it is not really a good choice, as the needle is stretching and making creases that make it difficult, and the end result is untidy and imprecise.

The making thread contains usually 6 individual, and sometimes 8 threads. It is made of cotton, and the quality depends on the portrait. Each nicket of this thread can be separated separately from one another, if it is necessary to make the motive from a slim thread or thread with a smaller number of nor. The most used mauline variant of a mild gloss, while Pearl contains a thin layer of wax that provides better durability and less wear of the thread itself during the production of gobelin tapestry.

Another form of embroidery thread is a runolist thread that is composed of 4 interconnected nor. Specific to this type of thread is that one nitish can not be separated from the other, which means that the obesity is constantly the same and does not change.

When choosing a suitable canvas and a thread that is usually color, it is necessary to choose a needle to make the embroidery. The embroidery needle mainly has a larger head, ie a thread opening, as it is necessary to pull the thread with 6 or 8 ni. Another one that must be careful is the thickness of the needle itself, because if it is thick and the thread thin, the thread will not be able to complete the space of the canvas created when the needle itself in the canvas. Quite the opposite, if the needle is thin and the thread has a large number of nor, due to the small space of the needle made of a large friction, a quick wear of the thread, and the result will be often shooting the thread. This means that the thickness of the needle and the thread must be harmonized to get a nice stroke and avoid problems in the processing process.

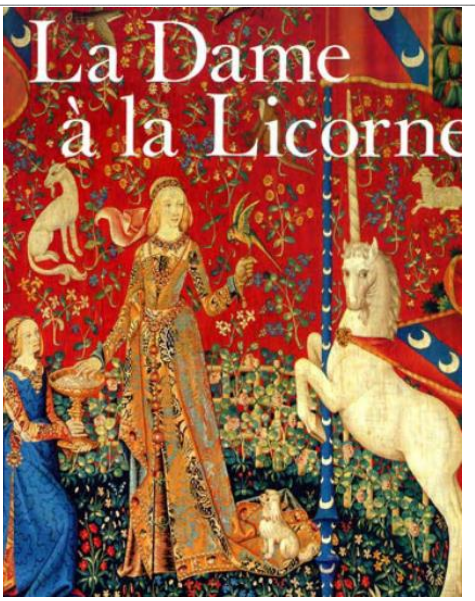

Figure 3: The Lady and Unicorn, “Cluny“ museum in Paris [9]

As part of the wider artistic movements of modern art, a process of research through radical experiments begins since the mid - 20th century. This is the application of new textile techniques and materials, to play with color, texture and shape, to the building of certificates with voluminous and sulpural forms and it puts all goblin to a deep artistic context. According to Mildred Constantine and Jack Lenor Larsen historians and theorists of the modern wallpaper and goblen set up a view that the modern wallpaper and tapestry means the use of traditional textile techniques and new materials, defining it as art of textiles.

The basic definition of Kuenzi is based on a line, a basic network and a free composition weaving, converting to visual art. The thread used is the one that connects traditional and modern and is the bearer of cultural and historical narratives, but also as the transformation of the artistic concept. It is the most important building element of the poetry of the work. So it has been from the oldest times to this day.

In western Europe, starting from the 8th century, weaving and decorating textiles develops under the influence of the East, which with the presence of Islamic conquests on the way of life of rich layers of feudal society, contributing to its broad application. Values are one of the top achievements that time.

3. EXPERIMENTAL PART - APPLYING GOBELIN TAPESTRY IN MODERN CLOTHING

Romantic 19th - century scenes reflected on modern pieces of clothing, implemented on unique corsets, skirts and dresses.
No design is similar to the other because each of them is made manually. The pieces are usually a blend of different fabrics and plaques made on order.

Figure 4: Textile design – full embroidery technique [10]

Figure 5: Coat inspired by the tradition with a gifted, found in Macedonia, Krusevo

The model is inspired by the tapestries in the past and is a blend of traditional art and contemporary fashion. The long coat is centrally enriched with cheese and is combined with a careful choice of colors to achieve better aesthetics. It is made by highlighting the female figure. The golden gobelin tapestry, which is set on an internal chosen material in black, perfectly emphasizes the beauty of the goblin which is a traditional element, and shows how it can be inserted into contemporary clothing in a unique and artistic way. With the combination of colors the model itself gives a sense of power, luxury and cultural value. Tapesry was made by Dane Kuzmanoska-Nane from Krusevo born in 1932 (researcher Prof. Vangja Dimitrijeva-Kuzmanoska, making a modern second-cycle student Marija Ananijeva).

This model is not only a usually fashionable piece, but a holder of art and cultural message. These specimens of designed textiles show how they can be applied in clothing. Art is a human activity that is related to the senses, emotions and intellect. It can be said that art is inherent in man, which distinguishes it within nature and stands out from other living beings. In Europe since the end of the 18th century, this term mainly refers to the products of so -called beautiful arts, such as sculpture, painting, architecture, graphics, but also music and dance, poetry and literature. The kitchen, cinematography, theater, photography and digital art are later added. The classification of art is not universal and it seems impossible to look for simple classification.

The simplest definition of the term art is that it is man's work. It is a visa art and has changed over the centuries. Perhaps the most accepted definition is that it refers to all the creative and creative actions of man.

Textile shaping is part of the other art that has been shown by the existence of making and through this type of textile design has emerged many of its entities in a person's social life. Starting from the distant past with the prints of their own hands in Egypt, to the high textile creations of modern living, the shaped textiles circulated over the centuries as a framework of everyday, with the fact that first and foremost every living person uses some kind of clothing that first and first of the clothing of the tape of the tape of the tap On clothing, in various forms. First of all as coloring the hairs from which one fabric is made, so printing, embroidery, plunge and all the other remarks. The main transmitters of textile art are the well -known fabric craft factories, through fashion houses as the first messengers of their textile designs applied to clothing, to individuals who deal with this issue daily and contribute to their own use of simplicity in use.

The application of textile shaping in clothing occurs even by designing textiles as a basic need in human life. As a phenomenon, it is still in the traditional clothing of every nation, hence its whole conversion of traditional clothing in making new models that will be intended in the fashion and global world. In the world of design and modern clothing, all traditional motives used in the distant past occupy, and it is a bridge of connecting the formerly rich traditional creation in different world cultures to modern textile shaping in contemporary clothing. Every time requires its own trends and movements in everyday life, each culture has ownership aspirations that begin deep into the roots of one's own culture, and further in world traditional cultures, depending on the determination of the spiritual creation of an individual and by presenting its current or periodic inspiring spirit.

The application of textiles is very different and can be applied in the wardrobe to use in architecture and interior. The unique hand -woven textiles, decorative textiles - gobelin tapestries, are some of the methods used for these applications. All of this requires knowledge of history, dizan theory, etc.
With special combinations of artistic art experience, technology and technology are fabric as a special art product or work of art with over 5,000 years. This proves broadcasting of inspirations that the textile offers us as a material and field of study.

Figure 6: Artwork of textiles - technique full embroidery [11]

The gobelin tapestries often used the flowers on large and small, and then other types of ornaments were used to move into painting, sculpture and architecture according to the main artistic-visual forms. This kind of art needed the higher class people to emphasize their social position and through it to express their strength as a symbol of their status. The most famous design centers were in Belgium and France.
The works used flower, animal, plant and other similar motives, and through all these symbols many life situations were shown that were to be transmitted as an art form for a particular family that presented a life status or the conveying of family emotions if the applied art that was present in a certain period. Tapestry represents a structure that has replaced today's decorative and application structure in our homes.

Figure 7: Century tapestry in the museum - in Paris (GOBLLEN TECHNIQUE, a mixture of cotton, wool and rayon) [12]

Figure 8: Tapestry in museum “Cluny” 15 centry [13]

4. CONCLUSION

On the basis of research issues in this paper about the existence of this type of textile, more answers can be extracted, first of which in the field research in Northern Macedonia still exist these traditional textile mosaics that today shape every day in traditional houses and houses in our rural, Archetypes of them and then made an attempt to implement them in

modern clothing, which will find the application in modern living and dress of modern and sophisticated women.

In the knitting of the network itself or the strands, many fates of women have been fitted in these areas, who, through the nurturing of this textile art, have embraced their cultural and artistic achievements that have to this day sloping textile art mosaics from these spaces. The gobelin tapestries as a unique form obtained by handmade manage to merge the tradition with the aesthetic and modern society. Their craftsmanship has testified over the centuries of patience, love and dedication to the people who have made it. The motives were drawn from the everyday that surrounded them. It never loses value, on the contrary, its value is increasing because it is a unique and unique symbol of artistic textile creation that has been going on in our territory since the distant sixties and remained as a symbol of textiles to this day, and many of them have been destroyed, due to non -use. In the past they have mainly been a major decorative element in the home, while nowadays their application has been applied in contemporary fashion, textile and art design.

From this research it can be concluded that tapestry is not only a tradition, it is a living artwork that is constantly developing with new times and will certainly be for many years inexhaustible topic of scientific research not only as textile art but also on many other social aspects. The preservation and promotion of these creations is of great importance for nurturing our tradition and the traditions of all former Yugoslavia's prices for all future generations that will follow this process. This textile art can positively affect the artistic shaping of textiles of all researchers' elements. Especially prominent as suitable integration as an image in all new textile areas as frames. We conclude that researching traditional textile work in Northern Macedonia first affects the awareness of the cultural community in which the artistic creation of textiles took place thousands of years ago.

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THE HISTORICAL AESTHETICS OF EMPIRE, ROMANTICISM, VICTORIANISM, AND ART NOUVEAU AS INSPIRATION FOR CONTEMPORARY SUSTAINABILITY IN FASHION DESIGN

Professional paper
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ABSTRACT: *The study examines the possibilities for combining sustainable fashion design with historical aesthetics. A design experiment created seven women's garments inspired by the Empire, Romantic, Victorian, and Art Nouveau styles, using zero-waste approaches and biodegradable materials. The results show that sustainability does not limit but rather stimulates creativity and cultural reflection in fashion design.*

Keywords: *sustainable fashion design, aesthetics, Zero Waste, Piñatex, deadstock materials, biodegradable textiles, design experiment.*

ISTORIJSKA ESTETIKA AMPIRA, ROMANTIZMA, VIKTORIJANIZMA I SECESIJE KAO INSPIRACIJA ZA SAVREMENU ODRŽIVOST U MODNOM DIZAJNU

APSTRAKT: *Studija ispituje mogućnosti kombinovanja održivog modnog dizajna sa istorijskom estetikom. Dizajnerski eksperiment je stvorio sedam ženskih odevnih predmeta inspirisanih stilovima imperijalnog, romantičarskog, viktorijanskog i art nuvoa, koristeći pristupe bez otpada i biorazgradive materijale. Rezultati pokazuju da održivost ne ograničava, već podstiče kreativnost i kulturnu refleksiju u modnom dizajnu.*

Ključne reči: *održivi modni dizajn, estetika, bez otpada, pinjateks, materijali od ostataka, biorazgradivi tekstil, dizajnerski eksperiment.*

1. INTRODUCTION

In contemporary fashion design, there is an increasing awareness of the need to rethink production practices in the context of global environmental challenges. Sustainable fashion is no longer perceived as a niche trend but as an ethical and innovative approach that aims

to minimize the negative impact on the environment through the use of biodegradable, recycled, and deadstock materials; the implementation of zero-waste strategies; and the creation of long-lasting products with a conscious life cycle.

In parallel, in recent years there has been a return to historical styles as a source of inspiration and cultural depth in design. Styles from the Empire, Romanticism, Victorian, and Art Nouveau eras offer a rich visual and constructive base that allows for contemporary interpretation through sustainable practices.

The present study aims to explore the potential for the relationship between historical aesthetics and sustainable design by creating seven contemporary women's clothing pieces inspired by the above-mentioned styles through a design experiment. The goal is not only an aesthetic reconstruction of the past but also a functional adaptation to current ethical and technological standards in the fashion industry.

2. MATERIAL AND METHODS

This research uses a qualitative methodological approach, which aims to explore the interaction between historical fashion styles—Empire, Romanticism, Victorianism, and Art Nouveau—and the implementation of contemporary sustainable design practices. The methodology combines design experimentation, visual analysis, and principles of applied art design.

For this project, innovative and sustainable textile materials such as Piñatex (pineapple fiber textile), regenerated tulle and lace, deadstock silk, and organic satin were considered. Organic silk, linen, and cotton. Eco-alternatives to leather (incl. materials from grape waste). Bamboo viscose and Tencel. These materials were selected based on the principles of environmental friendliness, biodegradability, and visual compatibility with historical aesthetics.

Piñatex is an innovative textile created from pineapple leaf fibers, which is a sustainable alternative to leather. This material was developed by Ananas Anam after a five-year research process and is presented as a revolutionary product that “challenges the textile market” through its biodegradability, as well as ethics and functionality [5].

Other sustainable materials considered in this study are textiles made from food waste. These materials include Piñatex (pineapple fiber), apple skin, banana textile, and other biodegradable alternatives that demonstrate the potential of waste resources as a basis for ethical fashion innovation [6].

Other textile materials such as Tencel and cotton blends combine the advantages of natural and regenerated fibers. As shown by Badr et al. [1], these blends improve the UV protection, moisture absorption, and mechanical resistance of the fabrics, making them particularly suitable for modern sustainable clothing [1].

The present study applies the principles of sustainable fashion design, with an emphasis on the use of deadstock fabrics and zero-waste tailoring. As Gjoni et al. [4] emphasize, these strategies not only reduce textile waste but also stimulate creativity, promote a circular economy, and offer an ethical alternative to conventional production. In the current project, deadstock fabrics are used both in the main construction of the models and in decorative

and transformable elements, which is consistent with the principles of resource efficiency and aesthetic sustainability.

Seven models of contemporary clothing were created as part of an applied design experiment, using inspiration from historical fashion eras. Through careful selection of materials and the application of sustainable and zero-waste design approaches, an emphasis on aesthetics and functionality is achieved, transforming traditional lines in the context of sustainable fashion. During the creation of the models, the principles of sustainable fashion design were applied with an emphasis on zero-waste approaches through careful planning of the patterns, modular construction, and the implementation of residual textiles in decorative and constructive solutions. Similar to the concept presented by McQuillan [2], where zero waste practices are explored. This study examines the application of these strategies in contemporary pattern design and their interaction with historically inspired silhouettes.

With the help of a previous study [3], where historically stable forms of clothing are studied, a visual-morphological analysis is applied, which examines the specific elements of clothing for the studied Empire, Romanticism, Victorianism, and Art Nouveau styles of clothing. The analysis is based on observation, description, and comparison of the characteristic elements of clothing.

The graphics software MediBang Paint Pro (MediBang, Inc., Tokyo, Japan) was used to create the sketches.

3. RESULTS AND DISCUSSION

As a result of the design experiments, seven models of contemporary women's clothing were created, demonstrating the successful connection between historical inspiration and sustainable design practices. Each of the models is individually structured, built on the basis of the style characteristics of the specific fashion era. At the same time, the principles of sustainable consumption, zero-waste approaches, and the use of innovative materials are reflected.

Figure 1 presents developed models of contemporary women's clothing combining sustainable design with an emphasis on the past.

Figure 1(a) presents Model 1 of a contemporary dress with historical references and the use of sustainable materials. The model presents a complete vision of an evening dress that draws inspiration from fashion styles from different eras—Empire, Romanticism, Victorian, and Art Nouveau. At the same time, the principles of sustainable fashion and zero waste design are integrated. The upper part is inspired by the Victorian style, presented in the form of a corset made of recycled leather or pineapple fibers (which imitate leather). It emphasizes the shape of the body, but without using hard seams or metal or plastic underwires. The waist is high, typical of the Empire style, and is emphasized by soft drapery, conveying elegance and dynamism of the silhouette. The sleeves are long and widen towards the wrists. They are made of regenerated tulle and recycled lace, aiming to convey a romantic effect characteristic of romanticism. The lower part is presented as a

flared floor-length skirt, made of organic silk and regenerated linen, which provides freedom of movement.

Figure 1: Contemporary women's clothing with elements of the historical styles Empire, Romanticism, Victorian and Art Nouveau applying modern innovative sustainable materials and design methods

The structure of the skirt gives a smooth movement, typical of the classic elegance of the Empire style. The train is long but presented with a modular construction, which allows reuse and adaptation according to needs, ensuring functionality and durability. The train can be removed and at the same time be part of the skirt or used as a pearl. The model

features hand-embroidered floral motifs inherent in Art Nouveau, using natural threads. The principles of zero waste and minimal textile waste are applied, transforming them into 3D embossed floral decorative accents. The main colors of the model are cream-beige and ivory, which are a reference to classic elegance. Accents of pink, orange, and light blue are noticeable as a soft contrast in the embroidery. This model presents an innovative approach to historical aesthetics, combining modern ecological standards. The incorporation of sustainable materials and adaptive design makes the dress not only visually striking but also functional in the context of aesthetic fashion.

Figure 1(b) shows Model 2, which is an innovative evening dress that implements a sustainable textile strategy. The upper part is presented in an asymmetrical shape inspired by Art Nouveau. It is presented in the form of a bodice made of deadstock silk with a delicate sheen. Its shape emphasizes the silhouette in a sophisticated and modern approach. The asymmetry adds a geometric artistic character and dynamism. The sleeves are shaped with a balloon volume and are made of unused organic satin. They are dramatic and theatrical, giving the spirit of Romanticism, bringing softness and movement to the upper part of the model. They can also be a separate part of the outfit. The lower part of the model is represented by a multi-layered skirt made of several layers of recycled chiffon and deadstock lace. The construction is asymmetrical and conveys the effect of a dancing silhouette when the body moves. The main color solutions are the light pastel ranges of turquoise, peach, lavender, and champagne. Model 2 demonstrates an intelligent and responsible approach, implemented through the use of deadstock and recycled materials. Combining the historical references of Art Nouveau and Romanticism, together with the principles of sustainability, it offers a balance between artistry and ethics. Here, not only is waste reduced, but at the same time it inspires new ways to creatively reimagine models through the prism of modernity.

Figure 1(c) presents Model 3. This is an evening dress with historical references, using biomaterials. The upper part is shaped like a bodice, which structurally resembles a corset, thanks to the constructive-decorative seams. The corset imitates leather textiles, but without the use of animal materials. Pineapple fibers or an alternative to leather, which is made from grape waste, are used. The sleeves are long, freely expanding towards the wrists, inspired by romanticism. They are made of regenerated tulle. They are decorated with embroidered floral motifs along the edge, which gives the look a delicacy. The lower part is represented by an asymmetrical long skirt, inspired by the Art Nouveau style. It is built of several layers of Piñatex, simultaneously combining dynamism and experimentalism with sustainable materials. Thanks to the asymmetry applied to the structure, artistry and volume are observed, while the shape remains feminine and attractive. This model is finished with a long modular train that follows the principles of zero waste in construction. The color solutions for this model are caramel shades. As accents, bronze shades are noticeable, which are derived from the decorative style of Art Nouveau. There are also accents in black, which are a reference to the dark elegance of Victorian fashion. This model demonstrates a contemporary vision, combining the aesthetics of history with the implementation of an innovative approach and the use of sustainable materials.

Figure 1(d) presents Model 4. It combines both the romantic elegance of the Empire style with the minimalist sustainability of contemporary fashion. The upper part of the model follows the high waist, which is typical of the Empire silhouette, located just below the bust. From there, the dress freely unfolds into a freely falling A-line skirt. The overall cut is developed according to the principles of zero-waste cutting. The shape and volume are modeled through gathers, folds, and tightening. The sleeves are slightly gathered with a length to the elbows, which is typical of Empire-style dresses of the early 19th century. They are constructed from a rectangular piece of fabric, gathered at the shoulder, and finished with a cuff from the remaining pieces of fabric. The vision has a slight historical reference while at the same time respecting modern principles of functionality. The skirt is made of long rectangular panels that are joined with fine external seams, which emphasize the geometric purity of the design. For additional volume and freedom of movement, wedge-shaped inserts from leftover fabric are also included as an expression of careful resource planning. The material suitable for making this model is organic cotton, linen, or twill. The color solutions for the model are earthy colors, such as champagne, ochre, or powder, which emphasize the natural texture of the fabrics and at the same time give a muted elegance.

Figure 1(e) presents Model 5. It combines the sensual romanticism of the 19th-century style with the sustainable concept of contemporary fashion. The upper part of the model has a defined waist, shaped by a textile belt or tightening straps, without the need to cut the fabric. The silhouette is feminine and flowing, with volume in the sleeves and lower part, achieved by gatherings and ruffles. The overall construction is developed according to the principles of zero-waste cutting, with all elements being composed of rectangular and trapezoidal shapes. The sleeves have a characteristic “bouffe” shape, long to the wrist and gathered at the shoulders and cuffs. They are made of long, straight panels, finished with a decorative band of leftover textile stripes. The skirt is multi-layered, freely falling, and made of ribbons and ruffles, which are also constructed from leftovers between the main cuts. The look has a historical reference to Romanticism, while at the same time the model can be worn as a dress, tunic, or long top. Suitable fabrics include organic muslin, recycled viscose, and light silk. The color palette is pastel: rose ash, misty blue, and vintage gold with anthracite, which enhance the ethereal and nostalgic character of the look.

Figure 1(f) shows Model 6. It combines the austere elegance of Victorian style with the minimalist sustainability of contemporary zero-waste design. The upper part of the model includes a high stand collar, inspired by Victorian corsets, which is constructed by folding a rectangular panel. The sleeves are shaped like “leg of mutton,” which are voluminous at the top and narrowed towards the wrists. They are constructed from long rectangular parts with a gather at the shoulders and long cuffs made of leftover fabric strips. The silhouette in the upper part is shaped without a real corset but through the application of strategic gathers and fastenings that emphasize the figure. The skirt is long and flared, made of trapezoidal and rectangular panels. For additional volume, wedge-shaped elements obtained from the remaining material during cutting have been added. The vision has a clearly expressed historical stylistics but is adapted to modern times; this model can be worn as a dress or unbuttoned as a cloak. The fabrics used are heavy organic cotton,

recycled micro tulle, and thick linen. The color range includes rich, noble shades, such as burgundy and red, as well as inky blue.

Figure 1(g) shows Model 7. It combines the organic sophistication of the Art Nouveau style with a contemporary zero-waste aesthetic. The upper part of the model has an asymmetrical or wavy neckline, inspired by the natural forms of Art Nouveau, formed by folding and tightening fabric. The sleeves are long, with a slight cutout at the wrist, and are decorated with textile applications in the form of stylized leaves and flowers cut from remnants. They are composed of diagonal or straight panels so as to use the entire width of the material. The skirt is medium to long, with a free, “wavy” silhouette, built from radially arranged triangular and trapezoidal panels. The remnant pieces of fabric are used as decorative inserts or second layers. The model can be transformed and worn as a tunic, dress, or with an inverted front and back panel. Suitable fabrics for the model are Tencel, bamboo viscose, organic silk, or light hemp fabric. Color schemes include coral, aquamarine, and emerald green—tones that enhance the natural aesthetic of the design.

Applied to each of the models, visual-morphological analysis proves that historical aesthetics are not only not opposed to contemporary sustainable practices but can also be their ally. With their capabilities for functionality, the ability to transform, modularity, and the use of biodegradable and reusable materials, the thesis is confirmed that fashion can be ethical while also being innovative, beautiful, and culturally significant.

4. CONCLUSION

This study demonstrates that the connection between the styles of the past and contemporary sustainable design practices is not only possible but also extremely fruitful in terms of innovation in the fashion industry. With the seven models created, the designer illustrates how, through careful selection of materials, the application of sustainable and zero-waste principles. Also, with the strategic influence of the Empire, Romanticism, Victorian, and Art Nouveau styles, a balance between aesthetics, functionality, and ethics can be achieved.

The results confirmed that sustainable design is challenged with a new level of creativity and cultural awareness. With modularity, transformation, and intelligent integration of textile resources, the importance of design as a means of social and environmental responsibility is affirmed.

In the future, similar approaches can be extended to fashion design education programs, industrial practices, and sustainable production policies, which will help build a new world of haute couture where innovation goes hand in hand with respect for the past and care for the future.

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THE APPEARANCE OF WOMEN'S COSTUMES IN THE RENAISSANCE AS INSPIRATION FOR A NEW MODEL OF CONTEMPORARY WOMEN'S CLOTHING

Professional paper
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ABSTRACT: *This paper analyzes the Renaissance period, from the 14th to the 17th century. The clothing, designs and trends worn during this period are also presented. The new model realized in this paper is inspired by the fashion of thist period, but it has been redesigned in a new modern form. The model is creative and innovative for the modern fashion world, but also brings the past through hand-sewed applications, but with new contemporary interpretation. The unbreakable connection between the Renaissance and contemporary fashion is also given.*

Keywords: *Renaissance, trends, costumes, fashion, ornaments.*

IZGLED ŽENSKIH KOSTIMA U RENESANSI KAO INSPIRACIJA ZA NOVI MODEL SAVREMENE ŽENSKE ODEĆE

APSTRAKT: *Ovaj rad analizira period renesanse, od 14. do 17. veka. Takođe je predstavljena odeća, dizajn i trendovi koji su se nosili tokom tog perioda. Novi model realizovan u ovom radu inspirisan je modom tog perioda, ali je redizajniran u novom modernom obliku. Model je kreativan i inovativan za savremeni svet mode, ali donosi i prošlost kroz ručno šivene aplikacije, ali sa novom savremenom interpretacijom. Takođe je data neraskidiva veza između renesanse i savremene mode.*

Ključne reči: *renesansa, trendovi, kostimi, moda, ornamenti.*

1. INTRODUCTION

The Renaissance is known as a cultural and artistic movement that first appeared in Italy between the 14th and 16th centuries. It later spread throughout Europe to countries such as Germany, the Netherlands, England, France, Spain, and Portugal. The origins of Renaissance art can be traced to Italy in the late 13th and early 14th centuries. During this period, Italian artists and scholars found themselves inspired by the ideas and developments of classical Roman culture.
The Renaissance left behind a number of important works that have influenced artists for centuries, including the most recent phase of humanity. Many of the Renaissance creations had unique characteristics that entered the history of art. Paintings such as the Mona Lisa and The Last Supper, by Leonardo Da Vinci, have become emblems of Renaissance art that influence many artists today. On the other hand, sculptures such as David and the Pietà, by Michelangelo, are part of the cultural heritage that the Renaissance left to humanity. The Renaissance, on an intellectual level, allows human beings to understand that the past should not be forgotten and that many of its aspects can be key to the development of new ideas in modernity [1,2].

1.1 Fashion during the Renaissance

Fashion was a kind of status symbol during this period. The authorities began to seriously deal with class differences and the way of dressing, and they determined by law. Wealthy citizens and nobles wore expensive clothes decorated with embroidery, silk dresses, furs and belts. Ordinary citizens and peasants were not allowed to wear silk. They wore simple clothes without any decorations. Women, like men, wore their day dresses over linen shirts. They usually consisted of one or two parts. The one-piece dress was long from the shoulders to the feet. The upper part of the dress was made of sturdy material and resembled men's waistcoats, and in the middle of the 15th century it was replaced by a corset. The two-piece dress, on the other hand, consisted of a petticoat (linen shirt and skirt) and was a rather luxurious dress. The puffy petticoat, as it was called, was not hidden, and could be seen under the main dress in the area of the sleeves and around the neck.
Until the beginning of the 16th century, the style remained the same, the clothes gained volume - they became wider and more pleated. Over the years, the main elements of the clothes remained the same, and only the details changed, such as the sharpness of the cut, the height of the collar, the fullness of the material, depending on the wishes of the kings and queens.
Throughout the Renaissance period, women dressed differently, and the style of the collar often varied. In the middle of the 15th century, collars were high and rounded. Towards the end of the same century, this style changed and became a fashionable expression. The collar was most often made of lace or linen, and the lace strips were folded in the shape of the number eight.
The hair of aristocratic women was gathered in buns with large volume, decorated with pearls, hairpins or small hats that added height to the bun.

Men during this period most often wore layered clothing, which consisted of a silk shirt, vest, cloak, short trousers and socks. The silk shirt was the basic piece of clothing. Although the shirt was a symbol of the working class, hard work and the difficult life of the peasant. Nobles wore a vest or doublet over silk shirts. Over it, they wore a cloak, long and wide made of luxurious materials, which symbolized their elegance, wealth, and noble origin. A mandatory part were short trousers to the knees, under which they wore knee-length socks. Later, men began to wear helaks, and over them a knee-length tunic. The tunic had to be richly decorated along the edges, and a vest was worn over it [3].
Equally important parts of men's clothing were shoes and hats. During this period, men's shoes were deep, pointed, and most often worn indoors, while leather clogs with wooden soles were worn outside.
Towards the end of the 15th century, shoes became rounded and had a ribbon tied around the ankle. By the end of the Renaissance period, shoes were becoming thinner and lighter. Hats also contributed to the appearance of the Renaissance man, even being punished if they had their heads uncovered. They were often decorated with a luxurious feather, and sometimes with precious stones.
The clothing of the lower classes was simple in cut, colors and without decorations. The poor woman also wore a half-corset in the waist area, which ended just below the chest. Poor men, on the other hand, wore wider trousers, tied around the waist and around the legs [4,5].

1.2. Women's fashion in England during the Renaissance

The style of clothing worn by women in Renaissance England changed from year to year, but the basic styles remained the same. Women's clothing consisted of a tight bodice and an ankle-length skirt. The skirt had a higher neckline and was quite acceptable and fashionable. The clothing of upper-class women was quite heavy and inconvenient for movement. Women from the lower classes wore much lighter clothing because they did not have servants to help them dress. Their corsets were looser or they did not wear them at all [6,7].

1.3. Fashion trends in France during the Renaissance

Fashion in France was constantly changing, incorporating the latest fashion elements from different countries. Certain styles that were worn were adopted from England, Germany, Italy and Spain. The colors that prevailed were mostly bright colors such as red, yellow, purple, pink and green which were popular for both men and women.
French fashion was heavily influenced by Italian fashion as a result of the reign of Francis I. He was known for the opulence of his clothing and the use of silk. His effort and his desire for attention were especially outstanding when wearing satin that was branched with gold and purple velvet with various embroidery. Francis and his courtiers often wore linen shirts with flat collars, embroidered in black. Hats had ostrich feathers or they decorated with metal and gold badges. The sleeves were quite voluminous and contrasting fabrics were used to emphasize the voluminousness.

Figure 1: Marguerite de Navarre princess of France
Source: https://vb.com/margueritedenavarre/

The king's (Francis I) sister, Margherita of Navarre (Fig.1), was known for her modern style, she was quite fond of exquisite silhouettes, plunging necklines with elaborately cut sleeves and black capes. She also had a passion for pearls, delicate embroidery and patterns, and other rich gemstones. Marguerite de Navarre was also known as women of the Reformation. Because of her distinctive legacy, by Samuel Putnam she also has been called “The first modern woman”. Her unique position as both a royal and a reformist, a patron of both the arts and religious thoughts, makes Marguerite de Navarre an important historical figure, whose impact continues to inspire scholars, feminists, and intellectuals today [8, 9].

1.4. Fashion trends in Spain during the Renaissance

In contrast to the colorful splendor and elegance of England and France, the Spanish style was quite dark and solemn. Men and women wore simple clothes with little decoration. The shoulders “lost“ their volume and the sleeves became narrower. The skirts were short and slightly open. The colors of the fabrics were black, dark green, dark red and gray. The most commonly used were velvet and satin with a few pearl decorations. Titian is a good example of the heavy and rigid fashion in Spain (Fig. 2). The painting portrays a male figure set against a flat black background. He appears to be looking at an indefinite point to the left of the canvas, with his left arm laid on his knee. He could be pointing at his gloves, which were a fashion statement at the time. He is dressed in a black wide jacket and a white shirt, as dtstement of the fashion of the period. The man's gloved left hand holds a second leather glove, an accessory used by the most refined gentlemen of the time. His right hand is adorned with a golden ring, as a symbol of richness, and sapphire and a pearl necklace [10,11].

Figure 2: Titian - Man with a Glove painted c. 1520 It is part of the collections of the Musée du Louvre, Paris
Source: https://collections.louvre.fr/en/ark:/53355/cl010062290

1.5. Renaissance jewelry

In the 14th century, after a slow growth in the Middle Ages, Europe finally experienced the Renaissance. It brought with it a rapid development of art, technology, knowledge, science, and infrastructure. The Renaissance connected civilizations through new trade routes that resulted in the exchange of culture, religion, and technology. This gave the world access to rare raw materials and precious stones. During this period, precious raw materials in Europe came from different parts of the world, right into the hands of artists who transformed the raw stones into exquisite pieces of jewelry.

Renaissance goldsmiths were innovative and skilled in creating gold and gilded jewelry. They used a variety of techniques to create perfect pieces, including casting, forging, soldering, and welding. More advanced techniques included embossing, enameling, engraving, and filigree decoration. Craftsmen mastered these techniques, drawing on ancient traditions to create stunning pieces of jewelry for wealthy clients. Some of the more successful goldsmiths of the Renaissance included Lorenzo Ghiberti, who began his career in the late 14th century. He was followed by Sandro Boccitelli, Luca della Robbia, and Andrea del Verrocchio. The discovery and appropriation of artifacts from the New World, as well as raw materials from mines in Peru and Mexico, made gold readily available to goldsmiths during the Renaissance.

With the development of trade in the Renaissance, Europe became rich in a large number of raw materials, jewelry and precious stones. Very often they were cut, rounded or differently shaped, and sometimes forged. New types of jewelry with stones previously unknown, with new and specific designs, were also observed. The most famous were stones cut in a rectangular shape and those in a round shape. Due to the popularity of simple rectangular cuts, stones were often set in gold frames in the shape of a box.

Often jewelry from that time has irregular edges due to uneven processing of the corners. Some of the precious stones from this period included diamonds and rubies from India, lapis lazuli from Afghanistan, emeralds from Colombia, iolite from Sri Lanka and turquoise from Brazil. Beads were also very popular, especially in the Victorian Era. When it comes to pearls, imitation pearls first appeared in the Renaissance, and for that reason, a law was passed in Italy that prohibited the use and placement of fake jewelry.

Pendants were considered the most eminent piece of jewelry at the time. Replacing the brooch, pendants were worn hanging from long gold chains, pinned to the dress or worn on the belt. Carved to perfection, the pendants featured miniature sculptures with biblical motifs and monograms. They were also designed for partners who wanted to have their initials inscribed on jewelry.

Portraits from the Middle Ages show that women often covered their ears with hair. In the Renaissance, they began to wear earrings and proudly flaunt them. The most common earrings were pear-shaped and drop-shaped. They were made of precious stones or pearls. The ferronier was made with only one precious stone. This piece of jewelry served as an ornament and women wore it around their heads, with the precious stone in front, on their forehead. Other types of ornaments were decorated with pearls and precious stones, forming a solid chain that women wore in their hair. The Renaissance is a period in history in which all European countries began to experiment with fashion and jewelry. Over time, different jewelry designs developed, inspired by different cultures and religions. Antique Renaissance pieces are classic, expensive and timeless. The collectible historical copies, presented in our Renaissance collection, bear witness to the history of this era, while also showcasing the creativity of this wonderful period of innovation [12, 13].

2. EXPERIMENTAL

2.1. Design inspired by Renaissance

2.1.1. Inspiration for the model

Fashion is a complex phenomenon in philosophical, sociological, cultural and commercial terms. On the other hand, fashion trends are the main features of almost all major designer collections, they are actually an indicator of the direction in which fashion will move. Fashion forecasters are constantly looking for inspiring styles that are harbingers of the future, ideas that capture the mood and behavior of potential consumers at the moment and at the same time signal a new fashion trend.

The Renaissance period is a great inspiration for a creative mind. From luxurious materials to uniquely crafted details and decorations, the Renaissance represents a rich treasure trove of ideas for a large number of fashion designers. *“Everything old is new again”,* was the quote that was used as an inspiring moment in the creation of the new model [14, 15]. Marguerite de Navarre princess of France (1492-1549) was a writer, philosopher, diplomat, and Queen of Navarre, sister of King Francois I (Francis I of France, r. 1515-1547). She was taken as an inspiration for the new contemporary model of woman clothes. Not only her fashion sense, but also her entire personality, as a woman with the power of influence, a woman who supports change, a woman who is an inspiration to others with her intelligence. She is remembered as a great Renaissance woman who fully embodied

the better aspects of her age. Her modest influence and reformist spirit served as inspiration to create a new model of women's clothing that would encourage women's self-confidence, a model that would require boldness in presentation, a model that would merge the past and the future into one powerful present in which the woman is influential, powerful, but still modest and empathetic. The model expresses a woman's readiness for change, self-confidence, and her own power.

3. RESULT AND DISCUSSION

3.1. New redesigned model of women’s costume

The new model is made from a basic blouse and skirt cut. Additional parts of asymetric material are attached to the upper part. On the lower part, metal circles on the waist and metal plates that symbolize this period are sewn by hand.

Figure 3: The final appearance of the new model (front part)

а) б)

Figure 3: a) The final appearance of the new model (rear part) **b)** Handmade head accessory

The colors chosen for the model are orange and brown. The color orange signifies enthusiasm, fascination, creativity, encouragement and encouragement, as well as the period itself, which signifies rebirth, striving for something new. The color brown is often associated with the earth, solid and secure, at times sharp and empty. Overall, they signify power and security, for something new, different. The cut of the model emphasizes the female figure, with a dose of extravagance that is obtained through the metal accessories that are handmade as a memory of a this era when manual work was imperative. The length of the skirt symbolizes female elegance and dignity, and the shirt with accessories on the shoulders is synonymous with female strength and power. The model is complemented by a headbun decorated with hand-embroidered accessories. This ornament is a symbol of female power and prestige. The model overall expresses a woman's belief in her own worth and her own power.

4. CONCLUSION

Fashion is a complex phenomenon in philosophical, sociological, cultural and commercial terms. On the other hand, fashion trends are the main features of almost all major designer collections, they are actually an indicator of the direction in which fashion trends will move. The Renaissance left behind a number of important works that have influenced artists for centuries, including the most recent phase of humanity. Many of the Renaissance creations had unique characteristics that entered the history of art. Fashion was a kind of status symbol during this period. The authorities began to seriously deal with class differences and the way of dressing, and they determined by law. Wealthy citizens and nobles wore expensive clothes decorated with embroidery, silk dresses, furs and belts. Ordinary citizens and peasants were not allowed to wear silk. They wore simple clothes without any decorations. French fashion was heavily influenced by Italian fashion as a result of the reign of Francis I. He was known for the opulence of his clothing and the use of silk. Marguerite de Navarre was significant person in this time, she was also called “The first modern woman”. In contrast to the colorful splendor and elegance of England and France, the Spanish style was quite dark and solemn. Men and women wore simple clothes with little decoration. During this period, precious raw materials in Europe came from different parts of the world, right into the hands of artists who transformed the raw stones into exquisite pieces of jewelry. Renaissance goldsmiths were innovative and skilled in creating gold and gilded jewelry. With the development of trade in the Renaissance, Europe became rich in a large number of raw materials, jewelry and precious stones. Pendants were considered the most eminent piece of jewelry at the time. Replacing the brooch, pendants were worn hanging from long gold chains, pinned to the dress or worn on the belt.The Renaissance period is a great inspiration for a creative mind. From luxurious materials to uniquely crafted details and decorations, the Renaissance represents a rich treasure trove of ideas for a large number of fashion designers. *“Everything old is new again”,* was the quote that was used as an inspiring moment in the creation of the new model. Marguerite de Navarre princess of France was taken as an inspiration for the new contemporary model of woman clothes. Not only her fashion sense, but also her entire personality, as a woman with the power of influence, a woman who supports change, a woman who is an inspiration

to others with her intelligence. She will be remembered as a great Renaissance woman who fully embodied the better aspects of her age.

The new model is made from a basic blouse and skirt cut. Additional parts of asymetric material are attached to the upper part. On the lower part, metal circles on the waist and metal plates that symbolize this period are sewn by hand. The cut of the model emphasizes the female figure, with a dose of extravagance that is obtained through the metal accessories that are handmade as a memory of a this era when manual work was imperative. The new model overall expresses a woman's belief in her own worth and her own power. This model merge the past and the future into one powerful present in which the woman is influential, powerful, but still modest and empathetic.

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HENRY MOORE'S TAPESTRIES: THE TRANSFORMATION OF SCULPTORAL FORMS INTO TEXTILE ART

Review scientific paper
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ABSTRACT: *Henry Moore, one of the most significant sculptors of the 20th century, is best known for his monumental organic sculptures. Although primarily a sculptor, his artistic vision was also translated into the textile medium through a series of tapestries. In collaboration with the West Dean Tapestry Workshop, some of his drawings and graphics were adapted into large-scale tapestries, creating a unique fusion of contemporary art and traditional textile techniques. This paper explores the process of transforming Moore's works into tapestry form, analyzing how color, texture, and composition were adjusted to suit woven art. Special attention is given to the role of collaboration between the artist and tapestry makers, as well as the significance of these works in the context of contemporary art and the preservation of craft techniques.*

Keywords: *Henry Moore, tapestry, textile art, contemporary art, craft preservation.*

TAPISERIJE HENRIJA MURA: TRANSFORMACIJA SKULPTORALNIH FORMI U TEKSTILNU UMETNOST

APSTRAKT: *Henri Mur, jedan od najznačajnijih vajara 20. veka, najpoznatiji je po svojim monumentalnim organskim skulpturama. Iako prvenstveno vajar, njegova umetnička vizija pretočena je i u tekstilni medij kroz seriju tapiserija. U saradnji sa radionicom Tapiserija Vest Dean, neki od njegovih crteža i grafika su adaptirani u velike tapiserije, stvarajući jedinstvenu fuziju savremene umetnosti i tradicionalnih tekstilnih tehnika. Ovaj rad istražuje proces transformacije Murovih dela u formu tapiserije, analizirajući kako su boja, tekstura i kompozicija prilagođeni tako da odgovaraju tkanoj umetnosti. Posebna pažnja posvećena je ulozi saradnje umetnika i tapiserije, kao i značaju ovih dela u kontekstu savremene umetnosti i očuvanju zanatskih tehnika.*

Ključne reči: *Henri Mur, tapiserija, tekstilna umetnost, savremena umetnost, očuvanje zanata.*

1. INTRODUCTION

In the 20th century, tapestry gained importance. It became a powerful means of expression, not only because of its historical significance, but also because it provided opportunities to experiment with colors, textures, and compositions in a completely new way. Traditionally, tapestries have served both narrative and decorative functions, but they also have practical applications, such as thermal insulation of walls and sound absorption. Today, however, these utilitarian functions are no longer in the foreground; contemporary tapestries are primarily seen as autonomous works of art, which retain their aesthetic and conceptual value. Many notable artists, such as Matisse and Picasso, explored a variety of media, including ceramics, stained glass, and textiles. However, tapestry stands out due to its close connection with painting and drawing, as it enables faithful reproduction of original works with exceptional precision.

Henry Moore was one of the few modern artists who extended his creativity to the art of tapestry. In collaboration with the West Dean Tapestry Studio, the artist began adapting his drawings and sculptures for tapestries, opening a new dimension in his creativity. This medium allowed him to explore colors, textures, and compositions in a way that differed from his sculptural expression, yet was deeply rooted in his artistic principles. Moore's move into tapestry was a technical innovation and a link to an ancient weaving tradition, which he modernized and adapted to his vision. Through this work, he combined the contemporary aesthetic language with the rich history of the craft, creating works of art that are not only visually striking but also culturally significant, deeply rooted in modern art.

2. A NEW DIMENSION OF ART: MOORE AND TEXTILE RESEARCH

Henry Moore, one of the most prominent sculptors of the 20th century, is known for his monumental sculptures that explore the human figure and natural forms. The worldwide recognition of his sculptures is reflected in the elements that combine abstract forms with aspects of human anatomy. Moore's sculptures, such as Reclining Figure, set new standards in contemporary sculpture, and his artistic oeuvre profoundly influenced many generations of artists. Although primarily devoted to sculpture, Moore did not limit himself to one medium. From the 1940s, he began exploring other art forms, such as drawing, graphics, textile design, and tapestry. Tapestry allowed him to think about color, texture, and composition in a completely different way, using the complexity of weaving as a means of artistic expression.

This exploration period coincided with the broader artistic tendencies of post-war Britain, where artists were increasingly seeking different media to expand their creative boundaries. A significant moment in the field of textiles is his foray into textile design, which became popular among artists during the 1940s. Czech textile manufacturer, Zika Ascher, commissioned designs from famous artists Picasso, Derem, Matisse, and Sutherland for women's scarves, in any color and size, for a 90cm square of silk or rayon. Henry Moore

also received an offer. Devoting himself to this issue, Moore even filled four notebooks with sketches of textile designs. Ascher produced four fabric designs, which were applied to scarves, dresses, and furniture [1]. Although this segment of Henry Moore's artistic output is less explored, one of his fabric designs is known to have been applied to the dressing gown worn by Sally Gray in They Made Me a Fugitive (1947), and another to curtain fabrics in his family home on the Hoaglands estate [2][3].

Figure 1: Women's Barbed Wire Jacket, screen printed rayon, fabric design Henry Moore, designed for Company Ascher Ltd, circa 1946, today: Victoria & Albert Museum, London [16]
Figure 2: Henry Moore, headscarf, Family Group design, maker Ascher, 1949, London, today: Victoria & Albert Museum, London [17]

During the war, Moore's dedication to textile design resulted from his inability to engage in sculpture. Still, it is noticeable that these works continue the beginning narrative. Although the format and medium of textile design are far removed from Henry Moore's monumental bronze sculptures, his specific techniques and motifs on Ascher's rayon fabric reflect his distinctive sculptural approach to form. Moore used crayons, pencil, ink, gouache, and watercolor in his designs, combining different techniques to achieve the desired visual effects. When transferring these motifs to screen printing, the results reflected the expressive depth and rich texturality of Moore's original work [4].
These engagements were part of the British government's initiative to provide consumer goods to its citizens, despite wartime conditions and supply and working conditions restrictions. The inclusion of artists highlighted to the public, especially in the industry, the untapped potential in design among "big-name" artists, which was applied to textiles, wallpapers, ceramics, and other consumer goods. In the post-war period, numerous British textile companies devoted themselves to revitalizing textile design after a period of simple design and a modest, usually dark, color palette. The success of applying floral, geometric, or abstract elements did not bypass other countries either, and the interest in "big-name"

artists expanded [5]. Henry Moore also collaborated with the company David Whitehead & Sons Ltd, for which he designed fabric for furniture in 1954 [6].

3. A NEW DIMENSION OF ART: MOORE AND TEXTILE RESEARCH

In 1976, Henry Moore and his daughter Mary visited the West Dean Tapestry Studio's exhibition of young tapestries, where they were impressed by the work on display. Delighted by the studio's quality and artistic potential, Mary suggested to her father that they establish a collaboration and commission a series of tapestries based on his works [7]. West Dean Tapestry Studio is one of the UK's most important and respected tapestry studios [8]. West Dean College was founded in 1971 as a center for education and training in conservation and the visual and applied arts, inspired by the vision of Edward James, a British poet, collector, and great patron of the arts [9]. In line with James' ambition to support and preserve traditional craft skills in the art world, the West Dean Tapestry Studio was established in 1976 to continue the rich history of tapestry weaving, linking it to contemporary artistic practices [10]. Specializing in hand weaving, the studio created high-quality tapestries characterized by precision, rich color, and intricate weaving.

As Mary herself stated, Moore had worked before; a couple of tapestries were made according to his designs, about which very little is known today [7]. The oldest known tapestry in Moore's catalog of creations is the result of a collaboration with Dovecot Studio in Edinburgh, and today, its location and owner are unknown.[11] The preserved photographs show that the artist realized it as a paper transposition of one of his watercolor drawings. The process of enlarging the image from a small, detailed drawing required the patience, precision, and skill of experienced weavers, who carefully wove the layered shades of color into the very fabric itself. While faithfully conveying Moore's expressive visual language, this tapestry simultaneously reveals a new dimension to his work, introducing an unexpected complexity to his artistic expression [12].

From 1971 to 1974, Moore collaborated with Brose Patrick Studio in Scotland. In the catalog of his works, six tapestries are recorded that have not experienced public presentations at exhibitions, and the ownership of as many as five of them is unknown. Nevertheless, they are evident in their continuation of the set theme, which is transferred from the sculptor's oeuvre and the artist's drawing potential.

When the collaboration with the West Dean Tapestry Studio began in 1976, Mary Moore took on the job of selecting and overseeing interpretations of Moore's intimate watercolor drawings in tapestries, which were worked up from their almost miniature ratmeters to life-size human figures in this renowned studio. Following the example of Moore's previous tapestries, the basic motif, in the form of figures, usually women, as recognizable in his sculptural oeuvre, was transferred to this collection of 23 tapestries created between 1976 and 1986 [12].

The result was almost perfect reinterpretations of Moore's drawings, realized with extreme precision through the weaving technique. This undertaking was a technical challenge and required a deep understanding of Moore's art. With the help of exceptional weavers, including Eva-Louise Svensson, the tapestries have become a bridge between

contemporary artistic creation and traditional craft skills [13]. A key aspect of interpreting his drawings was the faithful transfer of colors, compositions, and textures to textiles. Moore's drawings and sculptures featured subtle techniques of shading and abstract lines, which in tapestries became a challenge to convey in yarns and fibers. West Dean weavers faced the complex challenge of conveying Moore's subtle nuances in the wool medium, an adaptation made possible by the natural properties of wool, including its ability to absorb dye and flexibility in processing. A fine woolen thread could be split into several thinner threads, allowing for endless combinations of colors and textures.

Figure 3: Henry Moore, Standing Figures Tapestry, woven at the Dovecot Studio in Edinburgh, 1950 [18]
Figure 4: Henry Moore, Standing figures, tapestries, 1973, 222.2 x 370.9 cm, Ownership The Leonard and Sophie Davis Fund: on loan to Fine Art Museums of San Francisco [19]

During this extremely long process, which lasted three and a half years, each weaver made key decisions at every stage of the work, from the choice of colors and their combinations to the thickness of the thread, weaving technique, and achieving the desired texture. These decisions required high precision and artistic intuition, making each tapestry a unique work of art.[10] The tapestries produced at the West Dean Tapestry Studio are Moore's best-known works in this field. Originally intended for the artist's family, they were not exhibited publicly for over a decade. They were premiered in 1980 at the Victoria and Albert Museum in London, after which they toured New Zealand, the United States, and Canada over the next five years. The last major exhibition of these tapestries was held in Hong Kong in 2021 [13].
Additionally, this project enabled the preservation of tapestry weaving art while giving it contemporary significance. Throughout history, tapestry has often been perceived as a secondary art form, primarily due to the technique's complexity and high production costs. It was also predominantly considered a craft skill. Because of this, Moore's tapestries did not immediately gain the attention they deserved, but they significantly changed the perception of this medium. Their presence in the contemporary artistic context demonstrates that tapestry can be an equally expressive artistic medium, capable of

conveying a creative vision as effectively as classical forms such as painting and sculpture [14].

Figure 5: Eva Louise Svensson showing Henry Moore the tapestry Two Seated Women and a Child, 1977 [12]
Figure 6: Henry Moore, Two Seated Women with Children, 1975, drawing, pencil, chalk, charcoal, watercolour, gouache, pen and ink, paper: 310 x 281 mm, private collection, UK [20]

Henry Moore believed that all his works, regardless of the medium in which they were created, were connected and mutually complementary. Although best known for his sculptures, drawing was a key component of his artistic creation, especially when he was working on his tapestries. They are an extended dimension of his creative expression, in which abstract forms from drawings were transformed into textile works, and he thought that this represented a great challenge for him.[7] "If it were just a color reproduction, I wouldn't be interested. Because it is a translation from one medium into another and must be different, you get the "surprise" [10].

4. MOORE'S DRAWINGS AS A BASIS FOR TAPESTRIES

Moore never made drawings specifically intended for tapestries, but as a sculptor, he had a keen eye for proportion and magnification. He could use this ability to judge which of his drawings could function as large tapestries. Eva-Louise Svensson, who ran the West Dean Tapestry Studio in the 1970s, noted: "He [Moore] was not interested in designing specifically for tapestry and was willing to leave the interpretation to the weavers, provided it was faithful to the original." Moore's drawings were based on his sculptures and abstract forms, so the selection of drawings for the tapestries was a delicate process. Based on his ability to "see" the enlargement of his drawings, Moore chose those that could easily be transformed into tapestries, retaining his artistic integrity [14].

Figure 7: Henry Moore, Three Reclining Women, One with a Child, 1975, drawing, pencil, wax crayon, watercolor, gouache, paper: 290 x 222 mm, The Henry Moore Foundation [20]
Figure 8: Henry Moore, Two Seated Women and a Child, 1977, tapestry, wool warp, wool weft, 212,5 x 269,5 cm, detail, private collection, UK [21]

The tapestries were created based on drawings from the 1940s, 1970s, and 1980s. Moore was completely devoted to sculpture during the sixties, and some were enlarged 12 times. The largest tapestry, *Three Fates*, required 18 months of work by two weavers and measures 240 x 330 cm. This composition was a particular favorite among weavers because it symbolically depicts the flow of life, from birth to death, through the act of spinning.
Made from wool, cotton, and silk, Moore's tapestries reflect his signature thematic obsessions: the mother and child, the female figure in a landscape, and various depictions of the human figure, including standing, sitting, and reclining. Moore employed a specific drawing technique, drawing lines vertically along the form and horizontally across, thereby depicting the body's curves and volumes. He called this technique "sectional drawing". He also used subtle lighting effects achieved with white wax crayon, further emphasizing the drama of the forms [14].
Moore's drawings were created using a variety of techniques and materials, including pencil, charcoal, pastel, chalk, felt-tip pen, wax crayon, Chinese ink, gouache, and watercolor. He would often deliberately submerge them underwater to soften the lines and achieve the effect of blurring the colors. Translating these specific effects into a woven medium was a huge challenge for the 11 weavers. They conveyed the characteristic lines, shades, and tonalities of colors with exceptional precision, and their superior skills in yarn dyeing enabled the perfect matching of tones. With careful preparatory work, they managed to avoid the pixelated grid effect, a common occurrence in tapestries when viewed up close. Instead, their tapestries are characterized by fluidity and richness of texture, approaching the aesthetic of large, hand-painted canvases [12].

Eight out of ten of Moore's tapestries are almost monochromatic, with a rich spectrum of gray tones subtly enriched with blues and pinks. Master weaver Evam-Louise Svensson is known to have dyed the wool to achieve the exact colors and also used multi-toned thread blending to faithfully convey the artist's original drawing style [15]. Thus, subtle tones of gray, pink, and blue in tapestries such as *Mother and Child* made it possible to achieve a deep effect of volume, similar to that of his bronze sculptures.
Working together, they created a series of monumental wall tapestries approximately eight times larger than the original drawings, allowing them to experience the sensual materiality of Moore's works on paper on a larger scale. This West Dean series is now considered Moore's most significant achievement in the medium of tapestry, and works from this collection have been exhibited at numerous prominent international exhibitions in the United Kingdom, New Zealand, the United States, Canada, and Hong Kong.

5. AESTHETICS AND SYMBOLISM IN MOORE'S TAPESTRIES

Henry Moore successfully conveyed the essential aspects of his sculpture through his tapestries, expanding them into a new, textile medium that enabled a deeper exploration of the symbolism of the human figure, natural forms, and inner states. Although the tapestries in his oeuvre represented a technical challenge, they were simultaneously a tool for exploring and developing the thematic and aesthetic depths that had already appeared in his sculptures. That is why the connection of sculpture and tapestry in Moore's work is not just a transition from one medium to another, but an opportunity to shape symbolic and aesthetic values that were simultaneously universal and personal.

5.1. Symbolism of mother and child

One of the key symbols that consistently appears in Moore's tapestries is the theme of mother and child, which has a deeply rooted place in his entire artistic oeuvre. The mother and child motif often dominates Moore's drawings, which is unsurprising given that the birth of his unit, Mary, in 1946 inspired some of his happiest sculptural works on motherhood. Later, with the birth of a grandson, this thematic preoccupation gained its full expression, deepening Moore's artistic vision of parenthood and family bonding [10].
Although Moore tackled this subject through various media, tapestry gave him a specific way to weave symbolism, using color and texture to shape and convey meaning. Figural representations of women and children stood out in the motifs of his tapestries and sculptures, symbolizing key values such as motherhood, protection, and deep human connection. This theme was not accidental, but Moore continuously explored fundamental human relationships throughout his work. He often depicted mothers protecting their children, which gave his works, both in sculpture and tapestry, a universal, archetypal dimension that reflects basic human emotions and values.
In the tapestry *Two Seated Women with Children*, which is based on one of Moore's drawings, soft and flowing lines dominate, forming a connection between the figures of mothers and their children. The curves of the body and intensified shadows create a sense of protection and intimacy.

Moore's use of color in tapestries such as *Two Seated Women and a Child* and *Two Seated Women with Children* is not accidental - the subtle tones of gray, pink and blue not only emphasize the emotional connection between mother and child, but also allow achieving a deep effect of volume, similar to the one he achieved in his sculptures. These colors and the textural complex impact of the weaving give the tapestry a three-dimensional experience reminiscent of Moore's bronze sculptures, particularly those depicting similar thematic motifs, such as Reclining Mother and Child. In this sense, Moore used tapestry as a bridge between drawing and sculpture, where symbolism and aesthetic value develop through a medium that is seemingly "clothing-like" and "softer," yet still carries the weight of emotional expression.

Figure 9: Henry Moore, Two Seated Women with Children, 1977, tapestry, wool warp, wool weft, 207 x 178 cm, private collection, UK [21]
Figure 10: Henry Moore, Two Seated Women with Children, detail [21]

5.2. A woman in a landscape and a human figure

Another key motif that Moore often explores in tapestries is the figure of a woman in a landscape. This motif serves as both an aesthetic expression and a symbolic code in many of his sculptures, such as *Reclining Woman* and *Woman with a Child*. In the tapestries, women are depicted as static figures and often intertwine with the surrounding space – the landscape, thus creating a dynamic reminiscent of Moore's sculptural compositions, which play with space and volume.

In the *Seated Woman* tapestry, lines create a dynamic between the woman's body and the surrounding space. At the same time, colors depict the subtle interaction between the body and the environment. Moore often employed this kind of connection between figure and landscape in his sculptures, as seen in *Standing Woman*, where the contours of the woman are composed of abstract volumes that blend seamlessly into the surroundings.

As in his sculptures, the tapestries use "sectional drawing", where lines are drawn vertically and horizontally, creating an impression of movement and rhythm. These characteristic lines enable Moore to highlight the forms of the female body as they blend into the natural environment, adding symbolism to the interconnectedness of women and nature. This motif has frequently appeared in his sculptural work.

5.3. Abstract figure in space

Moore's abstract figures in tapestries also represent an important part of his aesthetic and symbolic research. Through his sculptures, Moore created abstract forms that, although stylized, were deeply connected to the real human body and its emotional expressions. Due to the nature of weaving, these abstract figures become even more fluid and intangible in tapestries, yet they retain the same symbolism.

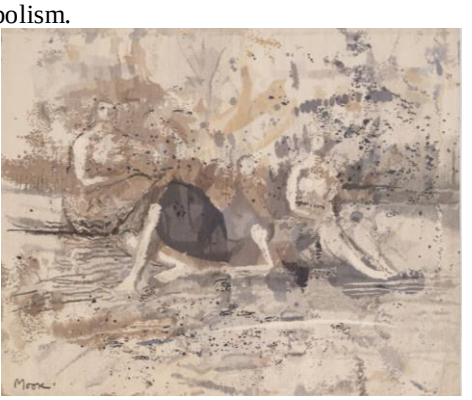

Figure 11: Henry Moore, Three Reclining Women with one Child, 1978, tapestry, wool warp, wool weft, 197 x 157 cm, private collection, UK [22]
Figure 12: Henry Moore, Three Women in Landscape, 1979, tapestry, wool warp, wool weft, 207 x 257 cm, private collection, UK [21]

The Three Fates tapestry depicts three abstract female figures that form a dynamic composition together. Like Moore's sculptures that explore the themes of fate, life, and death, this work symbolizes life's transience. In this work, weaving a tapestry, reminiscent of spinning, becomes a symbolic act of creation and destruction, life and death. The rich gray and blue tones, along with the complex textures, are reminiscent of the waves and textural effects that Moore often incorporated into his sculptures.

Moore's tapestries convey abstract forms from his sculptures, utilizing color, texture, and composition as vehicles for aesthetic expression. In many tapestries, colors were used to emphasize depth and volume, while weaving allowed for the creation of pronounced textural effects. These techniques were crucial in conveying emotions and symbols, whether in the form of a human figure, a landscape, or another motif.

Unlike his sculptures, Moore had to adapt to the technical challenges of weaving but retained his sculptural aesthetic. In the tapestries, he continued to use complex shapes, color gradients, and contrasts, but with an additional layer of symbolism, such as in *Mother and Child*, where the light effects of colors were used to emphasize the connection and security between the two figures, creating an almost physical experience.

6. CONCLUSION

Henry Moore's tapestries represent an extraordinary testimony of artistic transformation, where the essential elements of sculptural thinking are successfully transferred to the textile medium. Although at first glance they may seem like a departure from his primary expression, this segment of his oeuvre reveals a deep consistency in themes, forms, and symbolic language. The collaboration with the West Dean studio enabled the creation of a series of tapestries that are not only technically and professionally realized but also represent the fruit of a deep understanding between the artist and the weaver.
In these works, the motifs of mother and child, women in the landscape, and abstract human figures acquire a new material and emotional dimension. At the same time, the artist's experiment with textures and colors is transformed into a layered visual symphony. Moore saw the tapestry not as a mere reproduction, but as an act of translation from one medium to another, with all the challenges and surprises that process brings. Thanks to this approach, his tapestries today have the same artistic value and recognition as his sculptures. At the same time, this project contributed to the renewal of interest in tapestry art in the 20th century and opened a space for dialogue between traditional techniques and contemporary art. Moore's tapestry works can be interpreted as visual bridges between old and new, between drawing and form, between personal expression and collective cultural memory.

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SESSION III
MANAGEMENT AND MARKETING IN THE FASHION INDUSTRY

CONSUMER ATTITUDES TOWARDS FAST FASHION

Original scientific paper
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ABSTRACT: *Fast fashion, which encourages the constant change of trends and constantly drives the production of clothes that have a short lifespan and quickly become obsolete, creates the need for constant wardrobe renewal, which leads to the creation of enormous amounts of waste and a negative impact on the environment. On the other hand, more and more consumers are opting for slow and sustainable fashion clothes. The slow fashion movement is having a positive impact on the fashion industry. More and more people are aware of climate change and environmental pollution. As a result, the demand for sustainable, ethical fashion has grown since the beginning of the 21st century. The basic purpose of our research was to determine how fast fashion is driving changes in consumer shopping habits and identifying key factors that influence consumers' purchasing decisions when buying clothes.*

Keywords*: Fast fashion, slow fashion, fashion, consumer behaviour.*

STAVOVI POTROŠAČA PREMA BRZOJ MODI

APSTRAKT: *Brza moda, koja podstiče stalnu promenu trendova i stalno pokreće proizvodnju odeće koja ima kratak vek trajanja i brzo zastareva, stvara potrebu za stalnim obnavljanjem garderobe, što dovodi do stvaranja ogromnih količina otpada i negativnog uticaja na životnu sredinu. S druge strane, potrošači se odlučuju za odeću spore i održive mode. Pokret spore mode pozitivno utiče na modnu industriju. Sve više ljudi je svesno klimatskih promena i zagađenja životne sredine. Kao rezultat toga, potražnja za održivom, etičkom modom je porasla od početka 21. veka. Osnovni cilj našeg istraživanja bio je da utvrdimo koliko brza moda pokreće promene u navikama kupovine potrošača i da identifikujemo ključne faktore koji utiču na kupovne odluke potrošača pri kupovini odeće.*

Ključne reči: *Brza moda, spora moda, moda, ponašanje potrošača.*

1. INTRODUCTION

Fast fashion's impact on garment workers and the environment often leads to polarization because it raises questions about personal responsibility, ethical consumerism, and the industry's role in shaping our values and priorities. Some argue that it is the responsibility of individuals to make informed and ethical purchasing decisions and that choosing to support sustainable fashion brands is a way to promote better labour practices and reduce environmental harm [1].

The rise and success of fast fashion can be largely attributed to supply chain innovation. Highly agile, rapid response supply chains allow fast fashion retailers to respond to consumer demand and rapidly changing trends. Modern fashion consumption and the rise of ‘fast fashion’ has shifted consumer purchasing behaviour towards items of little perceived value with small economic and psychological investment required [2].

In this paper, we analysed the shopping behaviour consumers of fast fashion clothing, their attitudes towards the use of these clothes, and their opinions towards slow fashion clothing. Through our research, we found that consumers are increasingly environmentally aware and are buying more sustainable fashion clothing, even though it is slightly more expensive.

2. FAST FASHION AND CONSUMER BEHAVIOR

Fast fashion is a term used to describe the rapid production of cheap, low-quality clothing that often imitates popular styles from fashion labels, well-known brands, and independent designers. By constantly offering new trends at low prices, fast fashion brands such as Shein, Zara, and H&M encourage consumers to constantly buy more clothes. As a result, previous purchases, perhaps worn only a few times, are soon discarded. The rise of the fast fashion industry in the late 20th and early 21st centuries has had enormous consequences, from numerous environmental impacts to the exploitation of workers in the textile industry [3].

At first glance, fast fashion seems to be a democratization of style. Anyone can afford to be in fashion and the latest trends without spending a lot of money. However, this accessibility masks a deeper, more troubling reality. The low price of these clothes hides the high environmental and ethical cost of their production. From the overuse of natural resources to the exploitation of labour, the true cost of fast fashion is high, with the greatest toll on our planet [4].

In the modern world, it has become critical and essential for many people to constantly follow the trends that are prevalent in our society and media, especially in the world of fashion. Due to the greater number of trends emerging faster than before, the fast fashion industry has experienced a huge shift in advertising, especially with the rise of social media and influencers [5].

Adapting to emerging trends is crucial for brands in fashion industry to stay relevant and meet the evolving demands of their customers.

Consumers are more empowered to choose products that resonate with their own personal values, making brands more accountable for their business decisions. The fashion brands that can adapt most effectively to an ever-changing environment will be best positioned to maintain a great brand image [6].

Fashion trends come and go and fast-fashion giants are eager to capitalise on them. Unfortunately, there is a downside. The fashion industry is one of the most polluting industries in the world. As a result, the environmental impact of fashion is massive. Thankfully, another movement is gaining momentum: slow fashion [7].

Realistically, slow fashion and sustainable or ethical fashion have a lot of similarities. They are sister movements and follow the same general guidelines. The main difference with slow fashion is that it homes in on reducing consumption and production more specifically, harkening back to the pre-fast fashion era of our grandparents when clothing was a long-term investment rather than a throwaway hobby.

Slow fashion is an awareness and approach to fashion that carefully considers the processes and resources required to make clothing, and focusses on timeless, high-quality designs over trend-driven pieces destined for the landfill after a few wears.

Slow fashion opposes the fast fashion model that emerged around 30 years ago, in which clothes became cheaper, and trend cycles sped up. And despite ongoing sustainability efforts to close the loop in fashion, ultra-fast fashion brands like SHEIN are pumping out an alarming amount of poorly-made new styles every day. It’s clear that this philosophy is a necessary part of the movement.

Slow fashion has seen increasing support in the last few years as consumers demand higher sustainability and ethical standards. As research shows, 19% of the top fast fashion-related searches are linked to the environment, ethics, and sustainability. As awareness and popularity increases, the planet and all its inhabitants are set to benefit from this slower and more considered approach to fashion [8].

3. EMPIRICAL FINDINGS

We prepared a completely anonymous and short survey questionnaire on the web portal www.1ka.si. The link to the online questionnaire was shared via online social platforms Facebook, Instagram and TikTok. and. The total number of respondents for carrying out a market survey was 92 of this, 51 were men and 41 were women.

First, we wanted to know the age of the respondents.

Table 1: Age of the respondents

Age (years)	Frequency	Percent
Up to 18	**1**	**2%**
18-30	**39**	**58 %**
31-40	**18**	**25 %**
41-50	**14**	**8%**
51 and more	**10**	**7%**
Total	**92**	**100%**

In terms of age, most respondents were between 18 and 30 years old, representing 58% of all respondents. The age group between 31 and 40 years old comprised 25% of respondents. The groups between 41 and 50 years old and 51 years and over are equally represented, each with 7% of respondents (Table 1). The smallest group were respondents under 18 years old, representing only 2% of all respondents. This age distribution shows that the survey primarily covered a younger population, which allows us to gain insight into the shopping habits and attitudes towards fast fashion from the perspective of younger generations.
Then we were interested in how often respondents buy clothes.

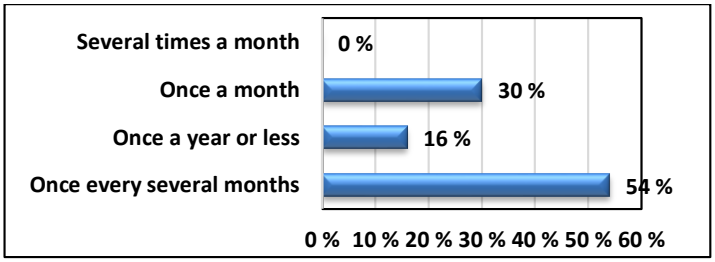

Figure 1: Frequency of purchasing clothes

To this question, most respondents (54%) (Figure 1) said they buy clothes once every few months. The second most common choice was once a month, which was indicated by 30% of participants. 16% of respondents shop less frequently, once a year or less. Interestingly, none of the respondents chose the option "several times a month." This distribution of answers suggests that most people buy clothes at slightly longer intervals, which may indicate more thoughtful shopping habits or a lesser need to intensively refresh their wardrobe.
We were also interested in what importance the respondents give to the negative impact of clothing on the environment

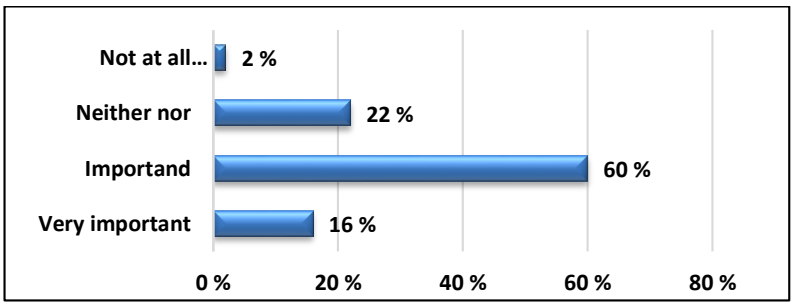

Figure 2: The importance of the negative impact of clothing on the environment

Most respondents (60%) consider that the absence of a negative impact on the environment is quite important in their purchasing decisions (Figure 2). This suggests that most consumers are aware of the environmental consequences of their purchases and try to avoid products that have a negative impact on the environment, although sustainability may not yet be the main factor in their decisions. However, it is surprising that 22% of respondents consider that the environmental aspect is not very important to them. This group of consumers may give priority to other factors such as price, design or brand, which indicates that sustainability is still not fully integrated into the general consumer mindset. In contrast, 16% of respondents stated that sustainability is very important to them, reflecting a group that is highly aware and probably more proactive in choosing sustainable products. However, 2% of respondents stated that the absence of a negative impact on the environment when buying clothes is not important to them at all. This small proportion suggests that there are individuals who completely ignore environmental aspects, which could be related to different personal priorities or a lack of knowledge about the consequences of fast fashion.

We were also interested in how long respondents wear or keep clothes before throwing them away.

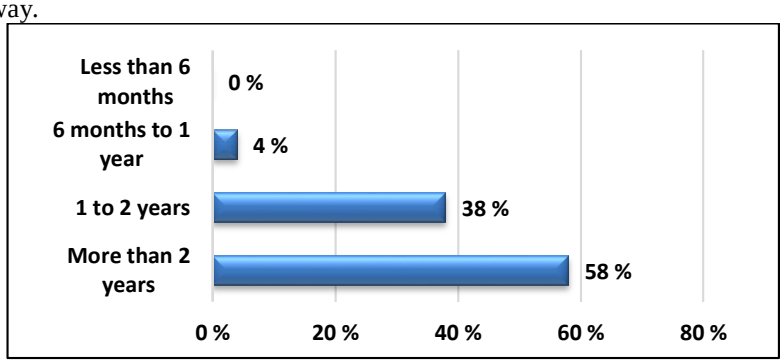

Figure 3: Time of use of clothing

As many as 58% of respondents said they keep clothes for more than two years. This may indicate a longer period of use for their clothes, but it is possible that many people keep clothes for this long because they simply forget about them due to the arrival of newer pieces (Figure 3). However, longer use contributes to reducing the need to constantly buy new clothes, which directly reduces the pressure on production and the associated environmental impacts.

Next is the group that keeps clothes for between one and two years, which represents 38% of respondents. This is still a relatively short period of time compared to longer periods, but it nevertheless indicates that clothes are not thrown away immediately after purchase. This group of consumers may not yet be fully committed to sustainable practices, but their use of clothes indicates a certain level of thoughtfulness. Their decision to replace clothes

within this timeframe is related to the desire to follow fashion trends, changes in personal style, or due to wear and tear.
Only 4% of respondents replace their clothes between six months and a year, indicating a practice of rapid clothing replacement. This figure is worrying, as it shows that this small proportion of consumers replace their clothes too quickly, which is typical of a faster consumption pattern and increases pressure on the environment.
The next question was about knowledge of the concept of fast fashion.

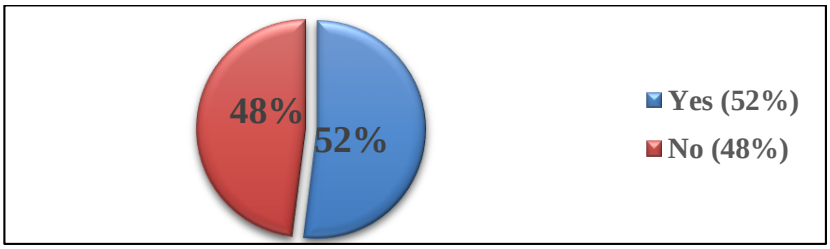

Figure 4: Understanding the concept of fast fashion

The responses show that most respondents (52%) are familiar with the term fast fashion, while 48% of respondents admitted that they are not familiar with the term (Figure 4). These results suggest that awareness of fast fashion is slowly increasing but is still not widespread enough to be considered a common topic among the public.
This lack of awareness means that many consumers may not understand the consequences of their purchasing decisions and the impact that fast fashion has on the environment and working conditions in the textile industry.
We also wanted to find out whether respondents were willing to pay more for environmentally friendly and more durable clothing.

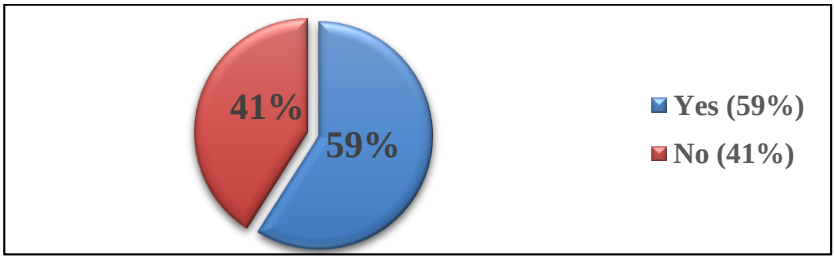

Figure 5: Respondents' willingness to pay more for environmentally friendly clothing

Almost 60% of respondents (59%) said they were willing to invest more in sustainable clothing, while 41% of respondents were not willing to pay higher prices for such products (Figure 5).
This means that almost two-thirds of respondents recognize the value of sustainable clothing and are willing to make a financial trade-off to contribute to a lower environmental impact. This willingness to pay more for sustainable products reflects a

growing awareness of the importance of sustainability and environmental care. The increased willingness to invest in environmentally friendly clothing may also indicate a change in consumer habits, where sustainability is valued as an important factor in purchasing decisions.

On the other hand, the 41% of respondents who are not willing to pay more point to a continued resistance to higher prices. This may indicate that for some consumers, price remains a key factor when purchasing clothing, regardless of the environmental benefits. It is possible that these consumers would need additional incentives, such as more affordable prices for sustainable products or additional information about long-term savings and environmental impacts, to change their attitude.

We wanted to find out from the respondents which factors are most important to them when buying clothes. They could choose from several factors.

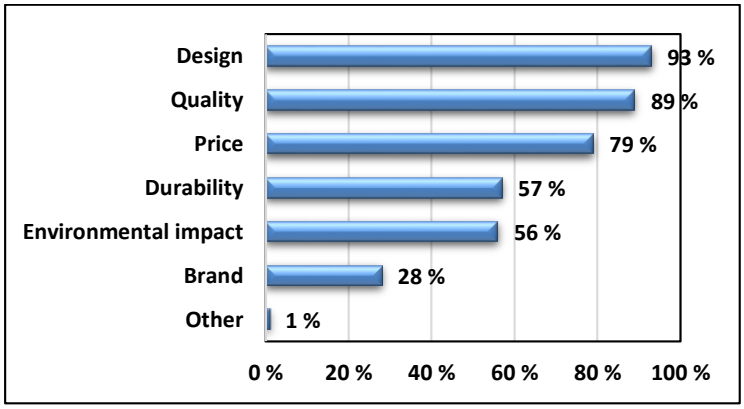

Figure 6: Important factors when buying clothes

The results showed (Figure 6) that the most important factor when buying clothes is design, chosen by 93% of respondents. Quality followed with 89% of choices, indicating that the durability and sustainability of the clothes is an important factor in the decision-making process. Price was important for 79% of respondents, meaning that despite being prepared to pay more for sustainable clothes, price still plays a key role in purchasing decisions.

CONCLUSION

An exploration of the phenomenon of fast fashion, which has become a globally dominant industry in recent decades with a tremendous impact on consumer behavior and the environment. Fast fashion has evolved in response to changing market demands, driven by consumers eager for the latest fashion trends at low prices. This business model, based on the rapid production and distribution of clothing, has enabled brands such as H&M and

Zara to bring new collections to the market in an extremely short time, often inspired by fashion shows or pop culture.

This shift in manufacturing allowed for a drastic reduction in costs, allowing for the mass production of clothing at extremely low prices. However, this model led to problematic practices such as labor exploitation, poor working conditions, and unethical practices. Along with the growth of the fast fashion industry, consumer habits also changed dramatically. Consumers began to quickly adapt their shopping habits to fast fashion, resulting in a constant demand for new and inexpensive products.

Our survey results showed that most respondents shop online and express a desire to buy more sustainable clothing, even if it means a slightly higher price. Respondents were willing to invest in sustainable clothing, even though half of the participants were not familiar with the term fast fashion. When choosing clothes, the most important factors for them are often design, quality and price, which shows that despite the growing awareness of sustainability issues, aesthetic and economic factors are still key in their decisions

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WOMEN'S SPORTSWEAR ON INSTAGRAM

Original scientific paper
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***ABSTRACT**: Social media is an extremely effective and successful tool for building and increasing brand awareness in the women's sportswear industry today, with Instagram being one of the most used social media platforms. Social media offers women's sportswear brands an extremely powerful tool for promoting products and services, as their broad presence and interactivity enable direct contact with the target group. Creative and attractively designed content, displayed in an innovative and imaginative way, is extremely important. The basic purpose of our research was to present alternative ways of using the social network Instagram for the purposes of marketing communication of women's sportswear brands and to examine the use of Instagram among active Instagram users in connection with women's sportswear.*

***Keywords**: women's sportswear, marketing communications, Instagram, social media.*

ŽENSKA SPORTSKA ODEĆA NA INSTAGRAMU

***APSTRAKT**: Društvene mreže su izuzetno efikasan i uspešan alat za izgradnju i povećanje prepoznatljivosti brenda u industriji ženske sportske odeće danas, a Instagram je jedna od najkorišćenijih platformi društvenih medija. Društvene mreže nude brendovima ženske sportske odeće izuzetno moćan alat za promociju proizvoda i usluga, jer njihovo široko prisustvo i interaktivnost omogućavaju direktan kontakt sa ciljnom grupom. Kreativan i atraktivno dizajniran sadržaj, prikazan na inovativan i maštovit način, izuzetno je važan. Osnovni cilj našeg istraživanja bio je da predstavimo alternativne načine korišćenja društvene mreže Instagram u svrhe marketinške komunikacije brendova ženske sportske odeće i da ispitamo korišćenje Instagrama među aktivnim korisnicima Instagrama u vezi sa ženskom sportskom odećom.*

***Ključne reči:** ženska sportska odeća, marketinške komunikacije, Instagram, društvene mreže.*

1. INTRODUCTION

Recently, technology has changed the online environment dramatically and the use of social media has proliferated. While social media advances people's lives, it also creates problems [1].
Sometimes it is believed that the use of print media, radio and television is sufficient to successfully and effectively establish relationships between a company (brand) and consumers, but with the digitization of the world and especially with the development of social networks, this has changed. People's habits and ways of communicating have changed, and consequently also the ways in which brands approach or communicate with their consumers.
Social networks, which are part of the so-called digital marketing, have become one of the most effective and indispensable tools for brand marketing communication, which not only allow companies to present products and services in a unique and extremely creative way, but also allow them to establish continuous personal interaction with consumers (long-term relationships) and strong empathy.
In this paper, we presented, defined and analysed in more detail the social network Instagram, its advantages, disadvantages and its use in women's sportswear shopping habits.

2. USING INSTAGRAM FOR WOMEN'S SPORTSWEAR

The social network Instagram is an online platform that was introduced in 2010 by Kevin Systrom, the founder of Instagram [2]. Initially, the platform served as a blog where individuals could share and present their stories, experiences and photos, but the view of Instagram quickly changed completely. People noticed the extraordinary potential of the application for sharing and exchanging high-quality photos and videos, designed with inspiration and encouragement, which led to a tremendous increase in the number of users and thus to the online platform we know today [3].
Nowadays, Instagram is the central online platform dedicated to creating, sharing and discovering high-quality, attractive visual content in the form of photos and videos. It stands out from other social platforms for its innovativeness, aesthetics and visually appealing nature, which makes the platform a magnet for all users who are enthusiasts of aesthetics, creativity and the fascination with visual content [4].
In the women's sportswear segment, companies have also quickly recognized the potential of Instagram and its business applications, which they can use for the purposes of effective marketing communication and reaching the target audience.
The strong emphasis on visual communication, namely, allows companies, especially in the women's sportswear sector, where visuality, aesthetics and creativity are extremely important factors, to tell and present stories about brands, products, their design inspirations, etc. in an original and unique way, while simultaneously creating a strong connection with the target audience. Also, according to many authors, in today's extremely competitive digital world, it is precisely visual content that is the most effective way to

connect with the audience and one of the strongest marketing strategies for companies in the women's sportswear segment [5].

Instagram has thus provided companies and brands in the women's sportswear segment with an ideal, aesthetically appealing virtual space, where they can not only present themselves, their products, services, etc. on a daily basis through unique visual creations, but also have the opportunity to establish continuous communication with their followers (target audience), which helps them to identify their needs, desires, feelings and opinions in a fairly simple way, so that they can continuously adjust further marketing campaigns, strategies and, last but not least, products. Continuous communication, together with all other factors, consequently, leads to an emotional connection with individuals on a much more personal level. In addition to direct marketing with the help of visual content displayed to the target group in an unobtrusive way, a strong community is created in parallel, which stands behind the company and the brand, supports it and trusts it immensely.

The Instagram social network primarily allows women's sportswear brands to open a business account, which gives them the opportunity to gain insight and use numerous advanced functionalities (analysis and metrics) that help the brand better understand the target audience, in terms of their desires, needs, opinions, wants, possible comments, etc. Based on the continuously monitored results and reactions of the target audience regarding published content, created marketing campaigns, sponsored posts, etc., fashion brands can consequently adapt further strategies, collections, products and planned further content for marketing purposes extremely quickly [6]. One of the key priority functionalities of Instagram for women's sportswear brands is advertising (Ads). Advertising on Instagram plays an indispensable role, as it allows for extremely precise targeting of published content according to various metrics of the target group (demographic factors, lifestyles, searched and liked content, ...). Such targeting of target groups is extremely valuable for women's sportswear brands, as they can reach exactly the desired individuals, members of the target group, with relatively low costs and investments in marketing campaigns (optimization of the financial budget for promotional purposes), without the need for additional investment in marketing campaigns [7]. The "Insights" function also allows women's sportswear brands to view information regarding designed ads (Ads) - posts, stories, videos, etc. and view data if the content was truly increased due to the financial investment (a greater number of people who saw the ads).

The social platform Instagram offers women's sportswear brands numerous advantages that they can use for digital marketing purposes [8]:

- attractive presentation of brands, products, services, various stories, etc.
- effective connection with the target audience (women, active Instagram users, sports fans, fashionable sportswear and healthy lifestyle) and establishment of strong connections.
- increasing brand recognition.
- the possibility of using different content formats for even greater engagement of the target audience.

- reaching a larger number of individuals (targeted targeting).
- cost-effectiveness (fewer financial investments, greater audience reach and greater profitability).
- increasing visibility using Ads
- insights into extremely accurate account statistics (Insights).
- easier collection of information about the target audience.
- tracking competitors and their marketing strategies.
- targeting women's sportswear brands' websites.

3. EMPIRICAL FINDINGS

We prepared a completely anonymous and short survey questionnaire on the web portal www.1ka.si. We chose a target population where we focused only on women. 155 women participated in the survey, of which 135 women answered the survey in full. The link to the online questionnaire was shared via online social platform Instagram.
First, we wanted to know the age of the respondents.

Table 1: Age of the respondents

Age (years)	Frequency	Percent
Up to 18	**0**	**0%**
18-24	**38**	**28 %**
25-34	**74**	**55 %**
35-44	**21**	**16%**
45 and more	**2**	**1%**
Total	**135**	**100%**

The survey included respondents from various age groups, with the largest number, 74, in the 25-34 age group. This was followed by 38 respondents in the 18-24 age group, and then 21 in the 35-44 age group. The least represented age group of respondents in the survey was the 45 and over age group, with 2 respondents, and no respondents in the under 18 age group.
We were also interested in the employment status of the respondents.

Table 2: Employment status of the respondents

Employment status	Frequency	Percent
Student	**18**	**14%**
Employed	**115**	**85 %**
Unemployed	**2**	**1 %**
Retired	**0**	**0%**
Total	**135**	**100%**

Table 2 shows that 85% of respondents were employed, 14% were students and 1% were unemployed.

With the next question, we wanted to find out how respondents followed women's sportswear brands.

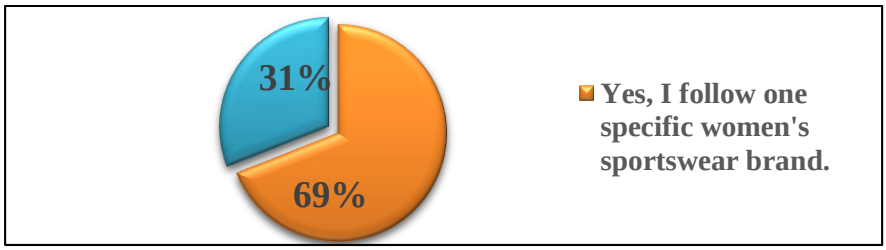

Chart 1: Following women's sportswear brands

The results shown in Chart 1 showed that among the respondents who participated in the study, the majority, 69%, follow one specific brand, while the remaining 31% follow a larger number of brands of women's sportswear.
Then we were interested in what factors make respondents start to trust a women's sportswear brand on Instagram. Since the survey questionnaire was closed-ended, we listed 8 factors for respondents, from which they could choose the 3 most important factors of trust for them.

Table 3: Key factors for trusting women's sportswear brands on Instagram

Factors of trust in women's sportswear brands on Instagram	Frequency	Percent
Visually appealing profile posts (high quality images and regular posting)	**62**	**46%**
Brand transparency (clear and honest communication)	**61**	**45 %**
Number of followers (higher the number, the more trust the brand)	**6**	**4 %**
Brand accessibility (interactivity with followers - active communication and response to comments, questions and messages)	**111**	**82 %**
Admitting mistakes	**59**	**44 %**
Choosing influencers/ambassadors	**14**	**10 %**
Creating entertaining content (product presentations, company events, etc.)	**14**	**10 %**

As can be seen from Table 3, among all the factors listed, the most, 111 respondents, chose the factor "Brand accessibility", which showed that for most participants, brand

interactivity and active communication are key to gaining their trust. The factors "Visually attractive content" and "Brand transparency" were also selected.

The results showed that both are approximately equivalent and almost equally important in gaining the trust of the respondents in women's sportswear brands. The factor "Visually attractive content" was chosen by 62 respondents, and brand transparency by 61 respondents. "Admitting mistakes", which was chosen as one of the key factors by 59 participants, was consequently ranked fourth in terms of the importance of the factor in gaining the trust of the respondents in women's sportswear brands. The last, fifth place was shared by the penultimate factor "Choosing influencers" and the last factor "Creating entertaining content", which were chosen by 14 respondents.

In the next question, we tested the usefulness of Instagram in relation to following and searching for women's sportswear from selected brands. We formulated 8 statements, and the respondents rated their level of agreement on a 5-point Likert scale from 1-5, where 1 meant "I completely disagree" and 5 meant "I completely agree". With the statement "Instagram allows me a wide insight into the details of women's sportswear of selected brands" we wanted to find out from the respondents whether they get enough information about ready-to-wear sizes, quality of materials, cuts, details on clothes, functionality of clothes, etc. with the help of Instagram.

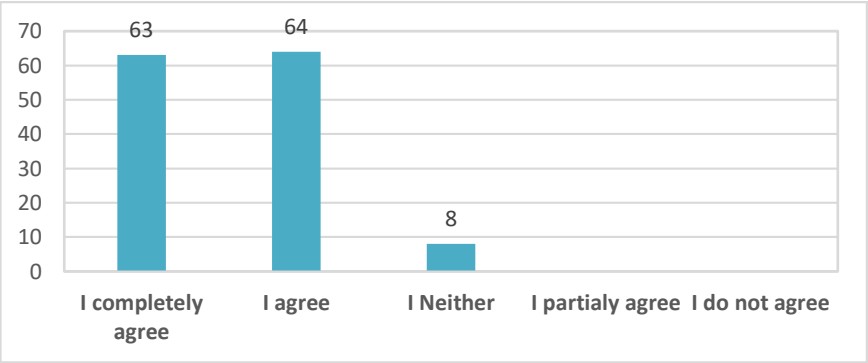

Chart 1: Following women's sportswear brands

Based on these results in Figure 1, we can conclude that users believe that Instagram is a sufficient source of information when searching for and following women's sportswear.

With the following question, we checked whether the respondents decide to visit online stores of women's sportswear brands based on the content they see on Instagram.

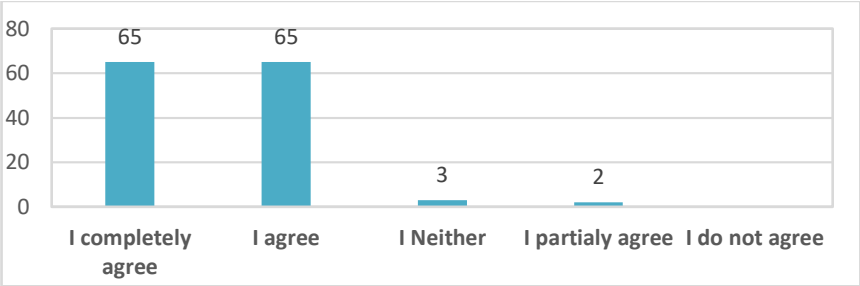

Figure 2: Purchasing decisions based on Instagram content

The results in Figure 2 showed that the content seen from women's sportswear brands influences the respondents' decision to visit online stores, as 65 of them completely agree with the statement, which means that these respondents decide to visit an online store of women's sportswear brands. Also, 65 respondents agreed with the statement, from which we can conclude that these respondents also visit online stores very often. 3 respondents remained undecided, and 2 were those who disagreed with the statement, which means that they usually do not decide to visit online stores of women's sportswear brands based on the content seen on Instagram.

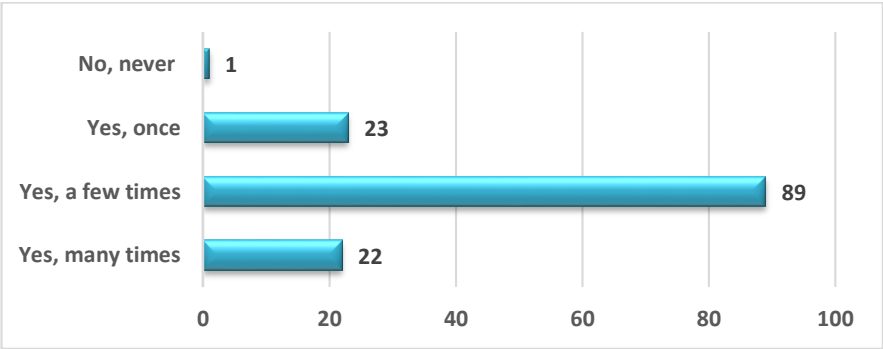

Figure 3: Decision on purchasing women's sportswear from selected brands - Instagram

4. CONCLUSION

The results of our research confirm the research of other authors that Instagram is the most aesthetically and creatively oriented social platform, which has opened the door to an extremely attractive virtual space for brands in the women's sportswear segment, where they not only have the opportunity to present themselves, products, upcoming collections, clothing manufacturing processes, etc. through unique creations, but they can also continuously communicate with followers and target audiences.

Continuous communication through various communication tools such as profile posts, Instagram Story, Instagram Live, Story Highlights, communication with the help of Influencers/ambassadors, Sponsored Posts, Prize Games, etc. primarily enables the transmission of content in various, individually attractive ways, and also enables constant monitoring, quick recognition and good understanding of the needs, desires and wants of the target audience, which allows brands to effectively adapt further marketing strategies. Based on its functionality, Instagram provides respondents with numerous attractive and interesting ways to follow content related to brands and women's sportswear.

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SPORTSWEAR PRODUCT DEVELOPMENT STRATEGY ADAPTED TO E-COMMERCE

Professional paper
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ABSTRACT: *E-commerce is present in all industries, as well as in the clothing industry. For successful e-commerce, a product development strategy is needed and its adaptation to the requirements of e-commerce. Market research shows that price is an important factor in making a customer interested in a product. In addition to price, website security, detailed product descriptions, variety and availability in large quantities are also important for customers. Whether the customer will be interested in the product depends on the customer's age as well as the customer's gender.*

Keywords: *E-commerce, development strategy, sportswear, product.*

STRATEGIJA RAZVOJA PROIZVODA SPORTSKE ODEĆE PRILAGOĐENOG E TRGOVINI

APSTRAKT: *E trgovina je zastupljena u svim industrijama, kao i u odevnoj industriji. Za uspešnu e trgovinu potrebna je sreategija razvoja proizvoda i njegovo prilagođavanje zahtevima E trgovine. Istraživanja tržišta pokazuju da je cena bitan fakror da se kupac zainteresuje za proizvod. Osim cene kupcima je bitna bezbednost sajta, detaljan opis proizvoda, raznolikost i dostupnost u više veličinskih brojeva. Da li će kupcu biti proizvod zanimljiv zavisi i od starosnog doba kupca kao i od pola kupca.*

Ključne reči: *E-trgovina, strategija razvoja, sportska odeća, proizvod.*

1. INTRODUCTION

Given that E-commerce has become a practice in most industries, the question is not whether to do business through E-commerce, but the question is which product

development strategies to apply in order to get as close as possible to online customers, their needs and habits.

E-commerce has its own specifics and target group. Products intended for sale on the Internet should be adapted to this type of sale, and they may differ from products sold in retail stores. This is particularly characteristic of the clothing industry, because customers need to feel the material from which the garment is made and to discover its fit to the body. Therefore, it is necessary to create a strategy for the development of products, existing and new, in order to correspond to E-commerce.

When revenue growth is planned based on the improvement of existing or the introduction of new products on the existing market, it is a product development strategy. The essence of this strategy is to use all the possibilities of the existing market, focusing on modifying the existing one and creating a new product. It is considered that the product development strategy has the highest risk especially in the case of inadequate analysis of the existing market. The product development strategy answers the question: why did we decide to stay on the existing market [1].

Introducing innovations into existing products requires an organization to spend a significant research budget. A product that has been innovated should be the result of an effort to respond more effectively to demand and be in line with the latest trends in the industry. As with other strategies, defining the marketing strategy is one of the priorities (distribution channels, promotional activities). The key features of the innovated products should be the following:

- They are more functional than previous versions of the product;
- Aesthetics are more challenging for consumers. But they resemble the previous version of the product;
- They provide a better user experience [1].

The product development strategy aims to extend the life cycle of the product. The analysis of the life cycle concluded that the product is in a phase of stagnation or even decline, so a modality of survival on the market is sought. Any drop in demand for a product should be a signal for deeper analysis and a potential decision to implement a product development strategy [1].

2. DESIGNING A SPORTS T-SHIRT MODEL FOR THE NEEDS OF E-COMMERCE

For the purposes of this research, a publication prepared as part of the initiative of the Ecommerce Association of Serbia (ECS) was used.

The first report entitled "E-commerce market research in the Republic of Serbia in 2023/2024" aims to systematically investigate all the participants present in the domestic e-commerce sector, while identifying obstacles that limit the growth and progress of e-commerce [2].

3,537 people participated in the research. The online shopping survey aimed to better understand the needs and habits of customers.

The results of the survey showed that clothing (sportswear), footwear or accessories represented a percentage of 69.8%, and sports equipment (including sportswear) with 28.5% (Figure 1). Given that clothing (including footwear and accessories) is the commodity that is most often purchased online, this paper will present a proposal for a designed model of a sports t-shirt.

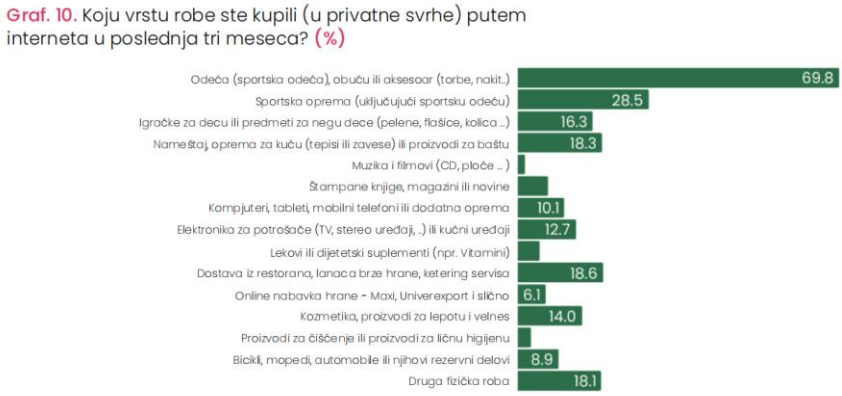

Figure 1: The result of the survey on the question: What kind of goods have you bought online in the last three months? [2]

According to the survey, 99.5% of respondents used online shopping, most often using a mobile phone in 62.3% and a desktop computer or laptop in 60.1%. 40.5% of respondents shopped online several times a month, 36% once a month, and 14.1% shopped several times a week. To the question: Do you think online shopping saves you time, 99% of respondents answered yes.

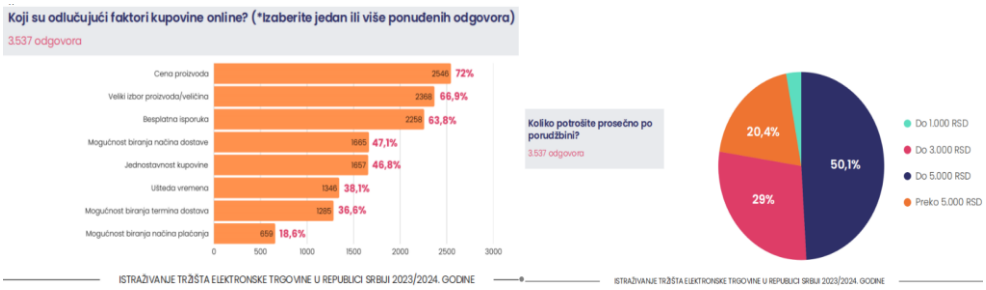

Figure 2: The result of the survey on the question: What are the decisive factors of online shopping?; How much do you spend on average per order?[2]

The decisive factors that make the customer decide to buy online are first of all the price of the product 72% of the respondents chose that answer, followed by a large selection of products and sizes 66.9%, free delivery 63.8% the possibility of choosing a delivery method (Figure 2).
According to the survey, 50.1% of customers spend up to 5000 RSD per order, 29% up to 3000 RSD and 20.4% over 5000 RSD (Figure 2).
Based on the results of the survey, it is possible to design a model of a women's sports shirt that would meet the expectations of customers: variety of models and sizes, price up to 5000 RSD, models that are interesting to the population from 18 to 45 years old (picture 3)

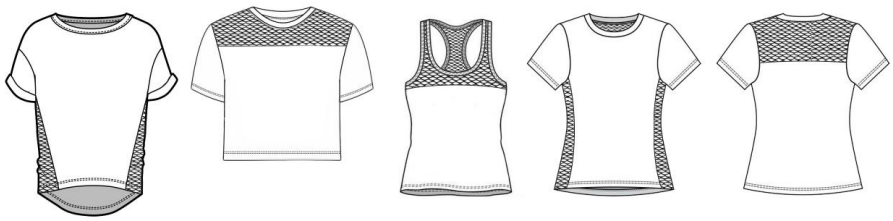

Figure 3: Models of sports women's shirts

The first model is an oversized t-shirt with a longer back, it can be worn for training or some daily activities, it also suits the older population. The side trim parts can be made of mesh or they can be made of the same material but in a different color
Another model is a crop top sports shirt, intended for the younger population, it can also be made in one material or in combination with mesh. It is intended for daily activities or fitness. This model is current among the younger population and combines well with leggings.
The sleeveless top, which is made of mesh in the upper part, emphasizes the shape of the body, is intended for yoga, pilates, fitness. This model is functional and breathable and is ideal for training. Special comfort can be given by seamless seams.
The fourth t-shirt with mesh details (Mesh Active Tee) has an ergonomic shape, good fit to the body, can be worn for various sports, including those that require long hours of activity. Additional comfort is provided by seamless seams.
These are the four basic models that can be made from different materials: Cotton, cotton in combination with elastin, polyester, polyamide... Each of the shirts can be made in a wider range of colors and sizes. Depending on whether the t-shirt is worn as a fashion item, the choice of material is cotton, viscose or with the addition of elastin, and sports t-shirts are made of wool, polyester, polyamide with the addition of elastin. Seamless seams are recommended on sports shirts. Also, each t-shirt has enough space to print a logo or a larger print on it, which additionally gives the possibility to create a larger number of models.
Given that the clothes have a lot of performance, it is difficult for the customer to conclude, based on the photo, how a particular model looks in real life. Therefore, it is necessary to

provide a detailed description of the model, the material it is made of, the raw material composition, the type of printing used, as well as a precise table of measurements. In the case of t-shirts that are intended for users who are more active in sports, it is necessary to write in the description of the t-shirt whether it is: Dry Fit, Quick Dry, whether the material has additional antibacterial protection of Poligiene that prevents the appearance of unpleasant odors, whether it has light reflective details... If wool were used for t-shirts with additional performance, the price would increase and the price range would be above 5000 RSD.

For new customers, it is extremely important that the website has a 63.4% security certificate. And for customers who shopped on the website, the most important factor in order to repeat the purchase is satisfaction with the service 86.9%, Loyalty card 76.1%. In addition to these benefits, customers are also attracted by seasonal sales and volume discounts.

According to the survey, in addition to the above requirements, customers also want to feel safe when shopping online. That is why their choice is cash on delivery, 67% of the respondents chose this method, online card 39%, card on delivery 15%, M banking 12%, E banking 11%. Most users are afraid of data theft 55.2%. One of the advantages of the domestic market (besides cheaper or free delivery) is that users prefer shopping at domestic online stores 61.7%, equally at foreign and domestic online stores 37.2%, foreign online stores 11.1%. 56.6% want home delivery, and 31.5% at parcel machines.

One of the disadvantages of E-commerce is the appearance of fraudsters on the market. One of the signs of abuse by advertisers is the use of urgency to encourage users to respond by clicking a link or replying to an email. Also messages starting with "free gift", "you've been chosen" or "you've won" should be avoided.

The rapid development of digital devices has enabled their use in various areas of electronic business. In parallel with the ubiquitous use of digital devices, various abuses and frauds have been enabled. [3]

3. CONCLUSION

E-commerce is no longer just trade that is expected in the future, E-commerce is trade that is currently intensively taking place and will be even more intensive in the future.

Many advantages of E-commerce compared to the classic way of trade, such as: saving time, significantly larger offer, availability from all over the world, overcoming linguistic and territorial distances, and many others, make E-commerce very desirable.

The development and representation of E-commerce is constantly increasing, which is expected in the future as well. For better business and success in online sales, it is necessary to know the habits of customers, their needs and fears. Online sales cause fear of fraud among customers, due to the appearance of fake websites, misuse of data, unauthorized withdrawal of funds from cards...

In the clothing industry, an additional requirement and disadvantage of E-commerce is that the customer cannot try on the garment, cannot feel the texture of the material and

cannot feel the fit of the garment. These shortcomings can be overcome with a good product description, adequate photos and accurate body measurement charts. If the manufacturer constantly maintains the quality of the product, using quality materials and a good fit, customers will gain trust and will very quickly know what they can get from that manufacturer and will always return to him.

In its offer, the manufacturer should be guided by the results of market research, he should take into account which population he is addressing, what are its habits and requirements. The manufacturer should offer a satisfactory number of items and size numbers. It should also take care of site security, payment options and favoring loyal customers.

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ANTICIPATION OF THE DEVELOPMENT OF DIGITAL TECHNOLOGIES OF E-BUSINESS

Professional paper
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ABSTRACT: *The anticipation of digital e-business technologies must basically rely on an expert assessment of elements of global business, the current state of e-business infrastructure, as well as elements of development tendencies and trends of business.*
The infrastructure of an e-business system is a set of platforms, networks, applications, as well as data and business rules for managing internal and external business processes and is based on Internet technologies (cloud computing, internet of things, big data, ubiquitous computing), which all together lead to rapid changes in business processes and influence the more efficient functioning and development of innovative business models.
On the other hand, today effective global business can be viewed through important components of work and business, such as the coexistence of traditional and digital sectors and the diffusion and implementation of innovative production technologies, with the tendencies of applied automation, flexible organizational innovations and the generating and inclusion of innovative materials and the circular economy, as well as the trends of quantitative-qualitative integration of human resources, smart specializations, flexible exploitation of technical textiles, consistent "cluster strategies" and efficient integration into the global market (with "elements of state protectionism"), etc., and on which the generating of globally adaptive, prosperous and intensively competitive companies is based. In addition to all the aforementioned elements, which are the basis of digital technology adoption in e-business, the adoption should also be viewed through the aspects of the development of the Internet of intelligent devices, context-aware computing, as well as the concept of augmented reality (which indicates an increasing adaptation to the characteristics of the environment), i.e. the basis of perhaps the key factors of the future development of e-business - the integration of artificial intelligence - AI and robotic automation - RPA. To the aforementioned elements, which are still applied to a certain extent today, anticipation must of course adequately consider, adopt and add the perfected elements of the big data segment, modern dynamic architecture of information systems,

elements of platforms without code (as a new era of inclusive digital empowerment), concepts of programmability of computer networks or so-called software-defined networks - SDN, as well as advanced analytics (through proactive strategies) and sustainability (through so-called hybrid and energy-efficient computing).
The work presents the most important elements of the current infrastructure of e-business, as well as the analysis of trends and tendencies of the work and development of the technical-technological segment, as the basis of effective anticipation of digital technologies of e-business, with special reference to the needs and application in the textile and clothing industry.

Ključne reči: *digitalne tehnologije, e-poslovanje, tendencije, trendovi, razvoj, anticipacija.*

ANTICIPACIJA RAZVOJA DIGITALNIH TEHNOLOGIJA E-POSLOVANJA

APSTRACT*: Anticipacija digitalnih tehnologija e-poslovanja se mora bazično oslanjati na ekspertsko sagledavanje elemenata globalnog poslovanja, trenutno stanje infrastrukture e-poslovanja, kao i elemente razvojnih tendencija i trendova poslovanja.*
Infrastruktura sistema e-poslovanja predstavlja skup platformi, mreža i aplikacija, kao i podataka i poslovnih pravila neophodnih za upravljanje internim i eksternim poslovnim procesima, a zasnovana je na internet tehnologijama (cloud computing, internet of things, big data, ubiquituos computing), što sve zajedno dovodi do brzih promena u poslovnim procesima i utiče na efikasnije funkcionisanje i razvoj inovativnih poslovnih modela.
Sa druge strane, danas se efikasno globalno poslovanje može sagledavati kroz važne komponente rada i poslovanja, kao što su koegzistencija tradicionalnog i digitalnog sektora i difuzija i implementacija inovativnih proizvodnih tehnologija, sa tendencijama aplikativnih automatizacija, fleksibilnih organizacionih inovacija i generisanja i inkluzije inovativnih materijala i cirkularne ekonomije, kao i trendovima kvantitativno-kvalitativnih integracija ljudskih resursa, pametnih specijalizacija, fleksibilnih eksploatacija tehničkog tekstila, konzistentnih "klaster strategija" i efikasnih integracija u globalno tržište (sa elementima „državnog protekcionizma"), itd., a na kojima se zasnivaju generisanja globalno adaptivnih, prosperitetnih i intezivno konkurentnih preduzeća. Uz sve navedene elemente, koji su osnova anicipacije digitalnih tehnologija u e-poslovanju, anicipacija bi se morala sagledavati i kroz aspekte razvoja interneta inteligentnih uredjaja, context-aware computing-a, kao i koncepta augmented reality-a (što ukazuje na sve veće prilagodjavanje karakteristikama okruženja), odnosno na osnove možda ključnih faktora budućeg razvoja e-poslovanja – integraciju veštačke inteligencije - AI i robotske automatizacije - RPA. Navedenim elementima, koji se i danas primenjuju u odredjenoj meri, anticipacija naravno mora adekvatno da sagleda, usvoji i pridoda usavršene elemente big data segmenta, modernu dinamičku arhitekturu informacionih sistema, elemente platformi bez koda (kao novu eru inkluzivnog digitalnog osnaživanja), koncepte programabilnosti računskih mreža ili tzv. softverskih definisanih mreža – SDN,

kao i naprednu analitiku (preko proaktivnih strategija) i održivost (kroz tzv. hibridno i energetski efikasno računarstvo).
Rad prezentuje najbitnije elemente aktuelne infrastrukture e-poslovanja, kao i analizu trendova i tendencija rada i razvoja tehničko-tehnološkog segmenta, kao osnove efikasne anticipacije digitalnih tehnologija e-poslovanja, sa posebnim osvrtom na potrebe i primenu u tekstilnoj i odevnoj industriji.

***Ključne reči**:digitalne tehnologije, e-poslovanje, tendencije, trendovi, razvoj,anticipacija.*

1. INTRODUCTION

Today, flexible business information systems are the focus of interest on the global market, which integrate human and technical resources, continuously develop innovative business processes and are capable of quick reaction to changing market demands, with the aim of achieving sustainable competitiveness in all business activities (because successful business today is reflected in the elements of high-quality and efficient functioning of business system components, such as speed, efficiency and optimization on the one hand, and globalization and strengthening competitiveness, on the other hand), are current and in the focus of interest on the global market.
In times of general and business globalization and digitization, the turn of the industrial sector, caused primarily by dynamic technical and technological development, but also by changed ways of thinking and consumer habits, is already shaping a new economy (as well as everyday life). In fact, the fact is that a modern and profitable industry, as well as the sustainable competitiveness of companies today, are unthinkable without timely and rapid implementation of quality and efficient process tools and complementary and adequate work and development strategies, with the inclusion and mass implementation of information communication - internet technologies, viewed through compatible and efficient business information systems (marketing, supply, payment, etc.), but also the so-called service information systems of education and continuous learning, effective health care of employees, state administration jobs, etc., as well as without innovative materials, adequate, fast and timely implementation of technical-technological and organizational innovations, cluster mode of business, market segmentation, close and flexible connection of production, production technologies, design and planning, with the possibility of quick response (Just In Time and Quick Response System), which all together indicate the needs of mass digitalization, as well as adaptation and development of quality and efficient information systems within the framework of new strategies e-business [1]. For a better assessment of the elements of business digitalization, in addition to the current elements, it is necessary to highlight the trends and tendencies of business, which are characterized on a global scale by: the development of a knowledge-based economy, innovative internet technologies and e-business, specialization of production and an increasingly shorter product life cycle, a high degree of interoperability, global supply chains, the development

of entrepreneurship and the small and medium-sized enterprise (SME) sector, the coherence of production technologies and flexible production, the creation of consistent values, and ultimately the coexistence of the traditional and newly created digitally transformed industrial sector [1, 2]. On the other hand, it is obvious that electronic business no longer represents only the implementation of new technologies, but radical changes in the way of thinking and viewing business processes, so it can be said that the key moment in new concepts of business is in fact conditioned by current technical-technological changes, as well as business tendencies and trends, with the "shifting" of business towards customers, fragmentation of products/production and defragmentation of the reproduction cycle, with enormous economic consequences of such trends that are reflected in the strengthening of new, modern and advanced industries based on the so-called high-tech technology [1, 3]. Today, the following can be singled out as advanced and innovative elements of modern business: digital platforms, internet portals, websites, online shops, Transaction Processing System (e-systems for processing transactions), Enterprise Resource Planning System (e-systems for resource planning), Supply Chain (e-systems for managing supply chains), Electronic Commerce Systems (e-commerce systems), Strategic Capability Network (strategic capabilities related to e-business), Product Lifecycle Management (e-systems for product life cycle management), Customer Relationship Management (e-systems for customer relationship management), etc. [3], which in the end directly points to the base of elements of successful anticipation through the far-reaching implementation of the innovative ICT sector and new ways of doing business.

Finally, it should be noted that digital transformation today goes beyond even the implementation of new technologies and represents the strategic adoption of innovative technologies, but with maximum use of all market opportunities of the company, and therefore continuous changes and improvement of information and communication technologies represent a key aspect of innovation in innovative e-business, which is precisely the reason why the anticipation of the development of digital e-business technologies in the coming period should be sought in these segments.

2. INFRASTRUCTURE OF ELECTRONIC BUSINESS

As electronic business and modern digital technologies today completely determine the w ay in which companies carry out business and represent a fundamental change, with clearly defined and visible advantages for all participants in business processes (companies, customers, stakeholders, society, etc.), it is obvious, considering the globalization of business and the conditions of the business environment, that the implementation of electronic business services is not enough to gain a competitive advantage, but it is necessary to develop innovative business strategies and models, with mass implementation, but also the maximum exploitation of the possibilities of ICT technologies, as well as the development and implementation of efficient compatible and adaptable information systems. Electronic business can also be presented as a set of business activities (optimization of business processes, improvement of public relations and other business support services), which take place through ICT technologies

(especially the Internet), which enable companies to connect and implement internal and external processes in a more efficient way (with characteristics such as speed, globalization, improvement of productivity, new clients and sharing of knowledge between organizations and institutions, etc.) [1, 3].

On the other hand, the search for elements to anticipate the digitalization of e-business must today start from the fact of the obvious cause-and-effect relationship between the two most important factors of e-business - the foundation or base and development of information and communication technologies and elements of business globalization, because the very inclusion of modern ICT technologies in business processes initiates the generation of new ways of doing business, as well as processes of business globalization (in relation to the environment or within the organization itself). And precisely because of this, it should be noted that the implementation of information technologies in business processes is primarily based on the exploitation of the components of the infrastructure of information technologies, which is otherwise based on ICT or internet technologies (web, cloud computing, internet of things, big data, ubiquitous computing, etc.), as an element of the possibility of rapid and efficient changes in business processes and rapid and efficient generation and development of new business models, which ultimately represents an important factor or resource in business processes of strategic positioning of companies. On the other hand, it should also be noted that the trends of implementing digitization or diffusion forms of implemented information systems, when generating innovative ways of doing business, represent the basis of the demand for a strong wave of e-business implementation, which obviously encourages the optimization of business processes and the strengthening of sustainable competitiveness through various service supports [1, 3].

ICT infrastructure is a set of technologies, platforms and services aimed at ensuring the smooth implementation of business activities in a company, because the requirements of modern business related to efficiency, cost optimization and scalability of infrastructure have led to the development of new approaches in the design and implementation of the same, while the infrastructure of e-business systems (which is a broader concept than ICT infrastructure) is a set of shared technical and technological resources (hardware, software, networks, products, applications, servers, operating systems, data and business rules, etc.), intended for the formation of platforms with applications for managing internal and external business processes. The infrastructure of e-business systems is based primarily on Internet technologies, such as cloud computing, the Internet of Things, the collection and mass processing of large amounts of data - big data, and ubiquitous computing, which ultimately enables rapid and adequate changes in business processes, influences the development of new and more efficient business models, and represents the basis of influencing factors and possible directions for the further development of digital e-business technologies [4, 5, 6]. It can be said that today, in the time of globalization and mass implementation and continuous improvement of ICT technologies, which increasingly and drastically "occupy" all the pores of the economy and society, and on the other hand with "unexpected" geostrategic changes, new value systems and business rules, and therefore the directions and ways of thinking and functioning of the world's largest

economies, it is really very ungrateful and complicated to anticipate the directions and elements of the development of digital technologies of e-business. However, since the e-business infrastructure can be singled out as one of the most important factors of influence on effective e-business, in this consideration, first of all, the idea of a fundamental and comprehensive analysis of the constituent elements of ICT infrastructure is imposed, then the analysis of other factors influencing the further development of e-business from the aspect of digital technologies, but also the analysis of tendencies and current trends of work and development, in order to eventually obtain real potential factors of influence of modern e-business in perspective, and thus the outlines of the anticipation of the development of digital e-business technology [5, 6]. Problems in such analyses and research mainly arise with information about the breadth of the e-business infrastructure, i.e. the fact that the ICT infrastructure consists of all areas of information technology (not including people, processes and documentation), which points to the problem of isolating only some elements for analysis, which also indicates that this is precisely why the process of quality and successful anticipation is reflected in expert knowledge, primarily in the field of ICT technologies, but also in the field of information systems of business activities, so this section will mention only some of the most important elements of the ICT infrastructure, as well as elements that are in trend, and whose further improvement should certainly be worked on:

- *Internet* - an infrastructure and communication technology and one of the main tools of the digital economy, with all the necessary supporting technologies, which in a short time has brought radical and intensive applications in business and global technical and technological development, and significantly influences the development and improvement of modern business. Like a catalyst, the Internet today drastically accelerates business and globalization processes, breaking down spatial and temporal limitations in the circulation of intangible goods, profiling product characteristics, forming a global market and fundamentally changing the relationship between producers and consumers, thus in fact represents the technical-technological basis for the creation of a new economic order, created as a result of the convergence of the implementation of digital technologies (computer, telecommunication and multimedia) [4, 5]. Today, the impact of the efficient exploitation of a key innovative technology - the Internet, as well as the Internet experience and improvements in ICT in the positive implications of the information technology (IT) infrastructure is increasingly evident, with companies using the Internet and digital technology to modernize and reorganize their businesses, as active drivers of digital transformations of business practices with increased competitiveness, sustainability and diversification. Even though the Internet functions as a single global network, with a current architecture that can be described as a set of logically interconnected entities (provider and user networks), it is actually a global decentralized information system of multiple autonomous local and global networks that are interconnected, with decentralization enabling network resilience to failures, while the very method of connecting autonomous entities into a single network is subject to constant change [4, 5]

- *Computer network* - enables communication and data exchange, and consists of computers and the network infrastructure (links - telephone and fiber optic cables, wireless signal, etc., and nodes - switches, routers, etc.) that connect them. The logical structure of modern computer networks used in business operations can be divided into levels: core layer (the central layer and the most critical point in the network that provides connectivity between distribution layer devices, and therefore requires the implementation of high-performance devices, as well as special attention to high availability and redundancy, i.e. it must support high data transfer speeds with low latency), distribution layer (the interface between the core and access layers and the access layer, with the task of providing data aggregation, as well as traffic flow control, using routing policies and defining broadcast domains) and access layer (represents the interface to end users and the connection of user devices - computers, printers, IP phones, etc., with the rest of the network and with the task of connecting to the network and controlling access) [4].
- *Cloud computing* - represents an abstracted, highly scalable and controlled computer infrastructure that hosts applications intended for end users. It is also a network of remote computers (owned by large companies), which are able to provide a range of services for the needs of individuals and organizations, from e-mail communication, through word processing programs, demanding applications for complex analysis of various types of data, to virtual storage space and a platform for the development of various applications, thus reducing the need for investments in IT infrastructure. Currently, three categories of cloud computing services are current: *Software as a Service* - software that is accessed via the Internet as a hosted service and has great potential for application in the field of information management at the individual level - time management applications, document management tools, word processing programs, analytical applications, e-mail clients, etc.), *Platform as a Service* - use of a platform provided by a PaaS service provider for application development, which eliminates the need to purchase necessary hardware and software resources, and *Infrastructure as a Service* - includes computer infrastructure, servers, data storage, networking, etc. in virtual space). Some of the most significant solutions based on cloud computing in the context of information management are e-mail communication (e.g. Google), document management (Google Docs) and business continuity [4, 7].
- *Virtual Private Networks* - VPNs are networks implemented on the public Internet network infrastructure, which use the same security and availability principles as private networks, as well as the management methods and quality of services provided by the Internet, and operate according to the principle of client-server architecture. It can also be said that VPN networks are a combination of tunneling technologies, encryption, access control, and services used to enable secure and protected intranet and extranet traffic on the Internet, with the process of configuring and creating a VPN itself being known as virtual private networking.

Tunneling is a technology that establishes an encrypted point-to-point connection between two computers and includes: encapsulation, transmission and decapsulation of packets transmitted over the network. The advantages of using VPN networks are connecting customers, suppliers and business partners in the global market, reducing telecommunications costs by using the Internet and using the existing Internet infrastructure, wider connectivity options, greater employee productivity, etc., while the disadvantages of VPN networks can primarily be highlighted as security problems and insufficient reliability, as well as potential incompatibility of different equipment manufacturers [4].

- The development of e-business applications in the *Internet environment* is conditioned by the requirements of modern information systems, with the degree of implementation depending on the architecture of information systems and available technologies. The possibility of increased processing power of client devices (computers, smartphones, tablet devices, etc.) represents a new challenge in the design of the architecture of information systems in the Internet environment. One of the most important technologies in the development of e-business applications is XML, as a standard that enables the transfer of data from the business logic layer to the presentation layer, and thanks to its hierarchical structure, it supports the existence of semantics and defines a set of standards for marking the structure and content of a document. It therefore represents one of the key technologies for achieving interoperability in e-business systems, as it enables their readability on different platforms and within different applications [4].
- *World Wide Web* – WWW is one of the most famous and most commonly used application-level Internet services, with standards for storing, retrieving, forming and presenting information on the Internet. In fact, it can be said that WWW is a network of links, text content and multimedia that represent the content of websites connected to the Internet, where access to WWW pages is defined by URL (Uniform Resource Locator) addresses, and the communication protocol in the network is HTTP (Hypertext Transfer Protocol). The development of modern business systems on the web implies comprehensiveness, a high level of complexity and quality of solutions, with minimal costs and a short timeframe, so application development frameworks are increasingly being used, which facilitates and accelerates application development, enables system modularity, improves security, etc. [4, 8].
- The basic technology of cloud computing is *virtualization* - the logical division of computing resources between multiple clients or the combination of multiple physical resources into one logical unit. The main advantages of implementing virtualization technologies are resource consolidation, energy saving, ease of maintenance, ease of creating system backups and system recovery, independence from the operating system, etc., so it can be said that virtualization actually enables scalability and cost-effectiveness of cloud infrastructure [4, 8].
- *Public Key Infrastructure* – as the security and protection of e-data and communications within and outside the company network are increasingly important elements of modern e-business, so too the public key infrastructure with

its constituent elements (cryptography, encryption, standards, protocols, etc.) represents one of the most important elements of the future of digital business.

- *Digital identity management* – represents a set of business processes and infrastructure for the creation, maintenance and use of digital identities, the application of which provides a tool for business automation. Since in modern computer architectures, data about entities (persons or resources) is distributed across various locations, it is necessary to establish adequate systems for managing digital identities (data that uniquely describes a person or resource and contains links between all entities). Digital identity management systems encompass authentication, authorization, security, and system access, and enable secure access to resources, effective access control, rapid change of identity-resource relationships, and protection of confidential information from unauthorized access [4]. Digital identity management is still an element that is being worked on today, but significant improvements in approaches to managing this element in a cloud environment are expected in the future.

The aforementioned trends, together with innovative technical-technological elements such as polyfunctional robots, neurological enhancements and ambient invisible intelligence, are likely guidelines and a database in looking at future development and creating anticipation of digital technologies of e-business and business processes, where artificial intelligence and digital platforms are likely to play a central role.

3. ANTICIPATION OF THE DEVELOPMENT OF DIGITAL TECHNOLOGIES

Based on all the above, it can be concluded that the anticipation of digital e-business technologies must basically rely on the current state of the e-business infrastructure, as well as an expert assessment of current trends, tendencies and possibilities of technical-technological development, but also variable elements of globalization, because dynamic technical-technological development, increasingly intense global connectivity, as well as changing consumer habits lay new foundations and a new era of electronic business. Today, it is already completely clear that information and communication technologies directly influence the improvement of business through the application of the concepts of business intelligence, supply chain management, e-logistics of transport, document management systems and accounting programs, as well as the concepts of electronic sales, internet marketing and public relations, so the anticipation of development should include and consider possible elements of advancement and improvement in these domains as well. Thus, in the coming period, the expansion of business models based on innovative digital technologies is expected in all areas, and thus the growing need for professionals with narrow expertise in the aforementioned areas, with the directions of further development being dictated by global trends in digital transformation and e-business, global connectivity and the increasing growth of the application of the Internet and ICT technologies, as well as changes in consumer expectations and the increasing emphasis on

ethical business and inclusiveness [8, 9, 10], so the following text will present and analyze some of the elements that need to be worked on and that need to be changed and improved, in order to represent the backbone and elements of the impact of development:

- One of such elements is certainly the Internet of intelligent devices - ***Internet of Things***, as a technology that ensures efficient connection of the digital and physical world through the intensive implementation and exploitation of increasingly perfect and compatible sensors and actuators, which on the other hand directly indicates the possibilities of automation and creation of the so-called smart environment, which together with the so-called Machine to Machine - M2M communication represents a critical element in the realization of the Internet of intelligent devices. Today, so-called smart environments rely primarily on sensor networks, which are composed of sensors and other devices distributed in space, which are in mutual communication and are used to monitor various physical phenomena - manifestations (temperature, light, sound, vibration, pressure, movement, etc.). Communication M2M communication networks enable two-way exchange of information with business applications, where HTTP (in combination with web services) is most often used as a communication protocol [11, 12, 13]. Thanks to this way of functioning, improvement and exploitation of technical means and tools, in practice, as a consequence, various segments of "smart" environments of production/business processes are increasingly present, as well as the so-called smart classrooms, houses, traffic, etc., which is a good incentive for further improvements, so this element should be included in the very top of the elements of the future development of digital technologies.
- Today, when computers are in use everywhere, ***ubiquitous computing*** does not seem like a special direction of development that needs to be particularly emphasized, but when it is treated as a combination of the Internet of intelligent devices and a smart environment on the one hand, and mobile and wearable computing on the other, with realization through smartphones, GSP, RFID, smart cards, etc., and unobtrusive or imperceptible distribution, but also continuous collection and processing of data at all times, then one can see the importance and uniqueness of this element, as well as the need to define it as an element of anticipation of the direction of development of digital technologies. In fact, the concept of ubiquitous computing should, above all, be based on systems that recognize and adapt to the characteristics of the environment (sensors, adapters, etc.), which represents the initial stage of the implementation of the so-called artificial intelligence, with the mass implementation of wearable components of computer innovative technologies, as well as devices that are in continuous interaction with users (clothes or shoes with sensors, smart watches or glasses, etc.) - which all together represent the so-called ***context-aware computing***.
- However, it should be noted that even better results of context-aware computing can be obtained in combination with techniques of the so-called augmented reality, i.e. in combination of data from the real environment with ***visualizations*** and ***virtualizations*** - which represents the so-called ***Augmented reality*** concept, where display devices (screen, cameras, etc.) are the main hardware components, because

they can provide the user with information and enable interaction in accordance with the environment in which they are located, which is an excellent recommendation for application in industrial design (e.g., a model of a future product can be displayed in space, a prototype upgrade, as well as displaying information about individual components and highlighting or hiding parts of the model) [11, 14]. It can be said that in addition to artificial intelligence, virtual reality (a computer model and abstract mental image of the real world that is stored on media and transmitted through space and time) and augmented reality (a variation of virtual reality in which the user can see the real world, i.e. the real environment is used as a background, combined with virtual objects), which are technologies that allow users to experience products before they buy them, will play an increasingly important role in modern business [11].

On the other hand, it should be noted that virtualization erases the traditional boundaries between hardware and software and significantly increases hardware utilization, which is one of the most important benefits of this element, as well as that in addition to data virtualization, it is also possible to achieve virtualization of networks, applications, desktops, servers, etc.. In connection with the above, it should be noted that 3D printing will also bring major changes and challenges in the areas of production and trade, because instead of selling physical products, there is the possibility of selling ***3D models***, which can be distributed over the Internet, and the user can print them on his 3D printer. 3D modeling enables quick and easy construction of objects of complex business models, adapted to virtual reality applications, but currently there are no fully defined standards for the integration of 3D content, or a clear methodological design for user interfaces that tightly integrate hypertext and interactive 3D graphics, which is why the development of modern Internet technologies and standards is expected in the coming period, which open up new opportunities for the transition to 3D web virtual realities (although they are already being applied today in engineering, medicine, biochemistry, art and industrial design, educational processes, etc.) [4].

It is obvious that one of the key factors in the development of electronic business is the ***integration of artificial intelligence - AI***, which is already used to personalize the user experience, analyze large amounts of data and optimize business processes, where the expectations of application and impact are even greater.

As artificial intelligence can autonomously analyze data, create customized proposals and enable faster responses to business challenges, it can be expected that it could completely change the way companies manage or make decisions. Thus, with a detailed review and analysis, it can be anticipated that in the coming period (the next five years), a critical mass of artificial intelligence implementation can already be expected, especially in the areas of e-commerce (sales and customer engagement), as well as in decision-making (at least 20-30 percent of business decisions). However, security, the degradation of human work and thinking, as well

as the interpretation of the positive and negative effects of implementation are already causing great debates and dilemmas about mass implementations of this element, which is why, with all the benefits brought by new technologies, and especially the technical-technological elements of artificial intelligence, it is necessary at the very beginning of mass implementations to choose and set them as the foundation, not as the future of technology [7, 15].

- Along with artificial intelligence, which brings the ability to learn from experiences, adapt to new contexts and overcome more complex challenges, technical-technological solutions and tools are necessary that are characterized by performing tasks with great precision, following programmed instructions, viewed through ***robotic process automation - RPA***. Of course, the synergy of these two, certainly the most influential technologies of today, is also necessary, which form a strong winning combination of two flexible systems with rapid adaptation to new requirements, in which robotic automation - RPA sets the pace, and artificial intelligence - AI brings the necessary intelligence to improve performance, whereby the mass application of robotic automation is expected above all in the segments of production (primarily on dangerous and boring jobs of large iterations) and supply - logistics (warehousing and transport) [7, 15].
- It is a fact that robotic process automation, as well as artificial intelligence, contain or represent a set of various ***ERP systems***, that is, a set of interconnected, compatible and connected information systems, accompanied by adequate technical and technological solutions. Seen from that aspect, a special segment should be highlighted - ***ERP systems based on the cloud***, because they enable real-time access and improve collaboration and decision-making, simplifying and facilitating upgrades and integration.

  Ultimately, all of this enables easier business optimization and faster implementation of innovations, transforming the way companies manage their business, thus enabling growth, enabling enhanced agility and economy of companies, as well as easier adaptation to changes. Of course, it is necessary to emphasize that it is necessary to improve this element of digital innovation and modern business, because by adopting an ERP system in the cloud, software updates become imperceptible, ERP systems can continuously monitor technological innovations, security is raised to a higher level, and the company's work is optimized by eliminating hardware costs and simplifying the maintenance of ICT infrastructure [7, 15]**.**
- One of the growing problems of the digital world and e-business is ***cyber security***, which is especially multiplied by the appearance of quantum computers that threaten to break the current asymmetric cryptography, which will affect data security and require the transition to the so-called post-quantum cryptography, which could and should provide effective resistance to decryption risks. Strong and effective current data security today implies the implementation of a zero-confidential ERP system with advanced encryption, reinforced by sophisticated verification processes - from multi-factor authentication of identification checks reinforced by artificial intelligence. In the coming period, increasing cyber

protection needs are expected, including security platforms, specific management tools and responsible use of artificial intelligence, in order to reduce security incidents [7].

- A significant role in the future of e-business (more precisely - e-commerce) will be played by the implementation and mass exploitation of ***cryptocurrency payments*** as well as ***Blockchain technology*** (decentralized database, composed of interconnected blocks of data), which can ensure transparency and security in transactions, reducing the possibility of fraud and increasing user trust. The benefits of using cryptocurrencies, which could become a standard payment method, are faster and cheaper transactions, especially in international business, while the true value and benefits of blockchain implementation can be seen in observing the process of digital trust, i.e. through process automation, cost reduction and increased efficiency through blockchain-based smart contracts. Of course, the digital component of these elements is still completely current today, but their commercialization and mass application would require more perfect, safer and cheaper opportunities, the improvements of which should be worked on (which will certainly encourage a technological revolution in many areas), regardless of what, or precisely because it currently seems as if the possibilities of using blockchain technology are unlimited [15, 16].
- The close cause-and-effect relationship between the possibility of the formation and existence of elements of artificial intelligence, virtualization, robotic automation of processes, etc., and the ***Big data*** element is obvious and inevitable, whereby a modern and efficient business today is unthinkable without the implementation and adequate and efficient exploitation of the Big data element (large and complex data sets of various formats, high processing speeds, volume and access, where traditional data processing applications are not applicable).
  In fact, Big Data element, which is already in widespread use, often refers not only to the size of the data set, but also includes the use of predictive analytics and other advanced methods for extracting value from data, as well as the design and implementation of a reliable, distributed, and scalable infrastructure for managing, analyzing, sharing, storing, and transferring large amounts of data. However, since the amounts of data used, as well as the processes of data search, analysis and visualization, are so large that it is not possible to process them with a standard approach and tools, the expectations for improvements in such concepts in the coming period are very high, i.e. the Big Data component is becoming the very top of the "top list" of elements of anticipation of the future development of digital e-business technologies, with special expectations of extensive and intensive applications in small and medium-sized enterprises. Traditional computer networks are otherwise based on a hierarchical model and can respond to standard requirements, whereby modern information systems involve a dynamic architecture, which requires certain changes in the approach to designing and implementing network infrastructure [13, 17, 18].

Future challenges in adopting big data technologies include designing and implementing infrastructure and storage services, as well as searching, analyzing, sharing, and visualizing large amounts of data, which offers certain industries the opportunity to generate competitive advantage, whereby ***software-defined networks*** (which operate on the principle of separating network management and data forwarding processes – the so-called ***concept of computer network programmability***) can successfully solve some of the above problems [19].

- Building software with ***no-code platforms*** has become a new reality because, by reducing dependence on technical teams, various sectors such as marketing, human resources and sales, thus facilitate innovation and application development, while increasing agility and reducing costs. All of the above leads to the process of mass digital transformations, so it can be said that the adoption of code-free platforms represents a new era of inclusive digital empowerment, and in the coming period, various innovative solutions in that area can be expected [7].
- Marketing and public relations are the elements of modern business that are changing the fastest today, accepting and implementing the elements and possibilities of digitalization, so it is expected to be the same in the future. A sufficient reason for one of the key elements of digital trends in marketing to be visualization or video content (which in the future can shape the future of the business world) is the data that shows that today over 90% of the world's population uses the Internet, and 60% is “on social networks", where about 90% of consumers use video content as a marketing tool, and almost the same percentage of consumers view video content and then make a purchase.

  Mobile marketing with SMS and MMS messages, mobile websites, bluetooth marketing, mobile applications, etc., on the one hand and smartphones as part of everyday life on the other hand, also represents a type of marketing on the rise, because it enables simple, cheap, highly responsive, targeted and personalized marketing activity in attracting individual consumers. Of course, a special place in the field of digital marketing, with all its specificities, is occupied by ***content marketing*** (blogs, podcasts, e-books, etc.), so-called ***influential marketing*** (with influencers), as well as ***social networks*** (Facebook, Instagram, Twitter, LinkedIn, etc.), whose further improvement and impact are expected in the coming period. Of course, in this area as well, an increasing application and strong influence of artificial intelligence is expected, which in the future will unambiguously influence the generation of all, including marketing strategies, as well as the business models of companies [11].
- One of the directions of further development of digital technologies of modern business will certainly be the development of ***mobile technologies***, taking into account that trends in mobile business technologies are moving towards the development of infrastructure for fast, reliable and secure transmission of large amounts of data through wireless media. Therefore, in the coming period, we should expect the dominance of mobile platforms, which will, on the other hand, be an ultimatum for companies to develop more intuitive and functional mobile solutions in order to attract and retain users. Of course, one of the basic

prerequisites for the development of mobile computing is the existence of mobile infrastructure, so one of the biggest challenges is the need to improve all types of mobile networks (WAN, MAN, LAN, PAN) by increasing data flow, and therefore the need for more efficient and secure collection, analysis and exploitation of the same [11].

- Finally, it should be noted that with the help of the so-called ***advanced analytics***, such as ***predictive***, ***prescriptive*** and ***diagnostic analytics***, or ***Text Mining*** and network analysis, and tools such as artificial intelligence, data mining, machine learning, etc., as well as proactive strategies, companies can turn the data they have into valuable insights, predicting trends, developing intelligent data processing models, optimizing operations and providing personalized user experiences, which are obvious and important causes of the improvement and advancement activities of this digital segment [7].

a. Digital transformation of e-business technologies - a special review of the textile and clothing industry

Business today can be viewed through the existence of innovative capacities, incentives and performance, which represent the elements of creating globally adaptive, prosperous and intensively competitive companies. It can be said that the generation of a modern and profitable industrial infrastructure with sustainable competitiveness of the textile and clothing industry is demonstrated through the digitization of business/production processes, the implementation of adequate information systems, elements of artificial intelligence, etc., but also through the adequate and timely implementation of organizational and technical-technological innovations, as well as the missions and visions of creative and original specializations [20].

On the other hand, the development and perspectives of digital technologies e-business of the company of textile and clothing industry must also be sought in the elements of the current infrastructure of production and business processes, as well as in work trends and development tendencies, and viewed partially, depending on the possibility of application and economic justification. Of course, all the mentioned elements will be applied in the process of digitization of the business processes of the company of textile and clothing industry, but due to specificitiesof this branch of the industry, some of the elements of digital technologies can be singled out and emphasized, which will be applied the fastest, most directly and most visibly and will significantly influence the further work and development of this branch of the industry, and thus, as some of the key trends for the next period, can be singled out:

- elements of *artificial intelligence* - technology that enables the creation of hyper-personalized recommendations, which will be based on a wide range of data, including the analysis of user behavior online, geolocation and even biometric data, thereby simplifying the provision of services, predicting demand and customer behavior, optimizing inventory management, empowering business and personalizing offers, effectively creating titles and descriptions customized SEO based on customer behavior, etc., improving operational efficiency. Ultimately, all

this optimizes processes and redefines the ways in which companies provide services, creating personalized user experiences that encourage operational efficiency and satisfaction, with a critical mass of implementation of this technology, primarily in the e-commerce segment (sales, customer engagement, etc.), marketing and public relations, but also logistics (by reducing delivery times and improving order accuracy), otherwise particularly important elements of the clothing industry;

- *Robotic process automation* - tedious and high-frequency tasks of the textile and clothing industry can be quickly solved by mass implementation of automation elements, as well as sensors and actuators, through various technical and technological innovations, primarily in the part of production processes (CAD/CAM systems), but also in parts of logistics - the storage and packaging segment, as well as the transport segment - delivery by autonomous vehicles and drones, which, on the other hand, will additionally affect the business phase of e-commerce, i.e. improvements to the efficient purchasing process.
- *Elements of augmented reality, visualization and virtualization - Augmented reality concept* is an excellent recommendation for application in industrial design, because in this way, for example, it is possible to display a model of a future product in space, while users can experience products before buying them, i.e. they can virtually try on a product (clothes, shoes, etc.), or even "visit" stores in virtual space, which can eliminate the uncertainty of online shopping and increase the trust and satisfaction of users. In connection with this, of course, the accelerated development of technologies that ensure the efficient connection of the digital and physical world is expected through the massive and precise implementation of the Internet, as well as the intensive implementation and exploitation of increasingly perfect compatible sensors and actuators - the *Internet of things strategy* [13, 14].
- Implementation and exploitation of *advanced analytics*, which companies enables to automatically update with accurate and relevant content, as well as optimization and simplified functioning of key functions of business processes (logistics, marketing, sales, etc.), with cost reduction, better understanding of users and achievement of comparative advantages that will lead to more successful operations of companies in the textile and clothing industry, but also with the increasingly massive exploitation of the so-called *virtual assistants or chatbots*, which through text messages communicate and provide assistance to users, without human intervention (especially interesting and applicable in marketing and public relations processes). Of course, there is a direct causal relationship with storage, speed and throughput, as well as the exploitation of large amounts of data, which is why the mass adoption of ***big data*** technologies can be expected in the coming period, which ultimately directly brings opportunities for generating competitive advantage to certain specific industrial sectors (e.g. the clothing industry).
- *Blockchain technology* - is another element of business modernization and digitization that can be expected to play a particularly significant role in e-commerce of textile and clothing industry companies in the future, because it can provide transparency and security in business and especially financial transactions,

reducing the possibility of fraud and increasing user trust, which is especially compatible with mass implementations of elements of artificial intelligence and personalization, virtualization and visualization, AR and one-click payment, advanced catalog management, etc., which can be expected in the following period.

- In the conditions of the current economic crisis, a particularly interesting option for smaller organizations (such as small and medium-sized enterprises of the textile and clothing industry, which normally make up over 90% of the total number of enterprises) is *cloud computing* - a network of remote computers that are able to provide a range of services for the needs of individuals and organizations, which primarily facilitates the manipulation and efficient exploitation of necessary data, but also drastically reduces the need for investments in ICT infrastructure.

4. CONCLUSION

In times of serious market disruption and the collapse of many business values and rules, as well as tectonic global economic and political disturbances, it is really very ungrateful to give development forecasts, especially forecasts of the development of the unstable and dependent on many elements of the digitization of e-business, so the anticipation of the development of digital technologies in e-business should logically follow on from an expert and analytical assessment of the current situation, as well as an assessment of the tendencies and trends of the operation and development of digital technologies, with a critical contemplative perception adequate areas of technical and technological innovation. Thus, it can be said that the anticipation of the development of digital technologies in e-business can be seen through aspects of the development of the Internet of intelligent devices (with emphasis on the development and implementation of sensors and actuators), as well as context-aware computing, but also augmented reality concepts, i.e. visualization and augmented and virtual reality, which indicates an increasing adaptation to the characteristics of the environment, i.e. the basis of perhaps the key factors of the future development of e-business - the integration of artificial intelligence and robotic automation. It should be emphasized that, regardless of all the expectations directed towards the implementation of artificial intelligence and robotic automation, it is necessary to insist on the fact that their implementation should not represent the future of technical-technological development, but primarily the base and tool of new technologies, represented in jobs dangerous to human health, as well as boring jobs with high frequency iterations. In addition to the above components, most of which are still in use to some extent today, we should also add the necessary expected development of the big data component, as well as elements of generating modern dynamic architectures of information systems, by introducing the concept of programmability of computer networks, i.e. software-defined networks. Anticipation, of course, must adequately consider the elements of the adoption of code-free platforms (as technological progress and entering a new era of inclusive digital empowerment),

advanced analytics (through transitions from reactive to proactive strategies), as well as elements of sustainability (through so-called hybrid and energy-efficient computing).

On the other hand, anticipation can be viewed from the aspect of major technical-technological changes and challenges of each segment of e-business separately, so for example in the area of production, increased implementation of CAD/CAM and robotic systems is expected, in the area of e-marketing - the increasing implementation, development and rise of video content, as well as content, mobile and influential marketing, while in the area of e-commerce it is further development and mass exploitation of social networks and improvement of mobile technology in terms of increasing the speed and flow of information, but also blockchain technology and the use of cryptocurrencies, and in logistics, these are the specifics of transport and delivery, as well as storage.

In the global world of fast fashion and e-commerce, the analysis, refinement and implementation of artificial intelligence and robotic automation, the so-called. fast sites, i.e. pages that load quickly and searches that give immediate results, augmented reality concepts in industrial design, advanced analytics in logistics, marketing or sales, with the continuous exploitation of big data elements, as well as simplified one-click payments, digital wallets and cryptocurrencies, personalized online experiences with the possibility of adjusting the price, promotional offers and product recommendations, will certainly be in the spotlight in the coming period, with automatic imposition of needs for technologies that will bring qualitative changes in the areas of security, efficiency and customization of digital tools.

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TEXTILE SOUVENIRS FROM SERBIA AS A TOURISM TREND

Professional paper
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ABSTRACT: *In this paper, the author examines the presentation of textile souvenirs from Serbia as an important and emerging trend in tourism, with the intention of highlighting the aesthetic and cultural value of these items. These souvenirs attract significant attention from visitors who travel with the aim of learning about and experiencing the cultural diversity of other regions. The focus of the research is on textile souvenirs that are frequently found at various tourist destinations, such as fairs, festivals, restaurants, hotels, and other venues that attract both domestic and international tourists. The author provides a brief overview of the main types of textile souvenirs produced in Serbia, paying particular attention to their traditional and artisanal characteristics. Additionally, the paper touches on notable tourism-related events in the region where these souvenirs are prominently featured. Through the use of economic indicators, the paper explores the integration of textile souvenirs within the broader framework of the marketing mix. In economic and marketing theory, the four primary components of the marketing mix are product, price, promotion, and place (often referred to as the "4Ps"). In the context of tourism, three additional components are frequently added: people, process (of service delivery), and physical evidence/environment. Together, these seven elements form what is known as the "7Ps" of the extended marketing mix, which is particularly relevant for service-based industries such as tourism. The concept of benchmarking in tourism is also addressed, with a comparative analysis of successful examples of souvenir marketing and sales in Serbia and neighboring countries. This comparative approach provides insight into best practices and effective strategies for enhancing the visibility and economic potential of textile souvenirs within the tourism sector. Furthermore, emphasizes the importance of preserving traditional customs and intangible cultural heritage through the use of authentic Serbian motifs and symbols in the design of tourist souvenirs. This not only supports local craftsmanship but also strengthens cultural identity and differentiation in a competitive global tourism market. The empirical part of the paper is based on survey research conducted among adult respondents. The study investigates their perceptions and attitudes regarding textile tourist souvenirs, the relationship between souvenirs and traditional textile crafts, and the perceived connection between these souvenirs and the elements of the marketing mix. The ultimate goal is to explore how textile souvenirs can contribute to the overall profitability and sustainability of tourism in Serbia.*

Keywords: *textile, souvenirs, tourism, marketing mix.*

TEKSTILNI SUVENIRI IZ SRBIJE KAO TURISTIČKI TREND

APSTRAKT: *U ovom radu autor se bavi predstavljanjem tekstilnih suvenira iz Srbije kao značajnog turističkog trenda u nameri da prikaže lepotu ovih predmeta koji privlače dužnu pažnju posetilaca koji putuju radi sticanja saznanja o različitosti kultura na drugim područjima. Akcenat u radu je na tekstilnim suvenirima koje se često pojavljuju na turističkim destinacijama tj. odredištima, sajmovima, festivalima, restoranima, hotelima... Autor ukratko opisuje vrste tekstilnih suvenira koje se izrađuju u Srbiji, osvrće se na turističke skupove u ovom regionu. Kroz ekonomske pokazatelje prikazuje prožimanje tekstilnih suvenira kroz elemente marketing miksa. U ekonomiji se primenjuju četiri elementa marketing miksa i to: proizvod, cena, promocija i prodaja koji se često nazivaju i „4P“. U turizmu se pored ovih elemenata primenjuju još tri: ljudi, procesi pružanja usluga i očuvanje okoline i često se svi zajedno nazivaju „7P“ elementi marketinig miksa. Benčmarking u turizmu predstavljen je kroz upoređivanje dobrih primera prodaje suvenira u Srbiji i okolnim zemljama. Takođe, autor se zalaže za očuvanje starih običaja kroz predstavljanje raznih motiva iz Srbije na turističkim suvenirima. Anketno istraživanje predstavljeno u radu sprovedeno je ispitivanjem punoletnih osoba. Sagledani su njihovi stavovi o pojmu tekstilnih turističkih suvenira; povezanosti suvenira sa tekstilnim zanatima; stavovi o korelaciji između turističkih suvenra posmatrani kroz elemente marketing miksa u cilju povećanja profita od turizma.*

Ključne reči: *tekstil, suveniri, turizam, marketnig miks.*

1. INTRODUCTION

The main purpose of this work was a comprehensive research of the concept, origin and application of textile souvenirs and its connection with the development of tourism in Serbia, as well as identifying the limiting factors of its development and formulating recommendations for potential policy holders of tourism development. In this paper, the author deals with the presentation of the history of the creation of souvenirs and textile souvenirs, as well as the economic relationship between them, viewed through the seven elements of the marketing mix in tourism. The author examines the ways of making textile souvenirs, the need for souvenirs and their distribution. It also advocates for the preservation of old handicrafts and small workshops as a significant tourist potential. Trends in tourism are constantly changing, especially fashion. Fast fashion is based on the constant creation of new styles based on them and sold at very low prices. It is based on cheap products.

The aim of the work is to point out the possibility of providing efforts to the development of tourism through constant innovation of the textile process in terms of making small but necessary products that tourists are happy to buy as a memory of their stay in another place or as a sign of the attention they pay by giving them to friends and relatives. The author

starts from the initial hypothesis of whether there is a correlation, i.e. interdependence between textile souvenirs and the development of tourism in Serbia. For this purpose, a statistical survey was carried out using the method of surveying one hundred random respondents on three important questions. The paper will also show several photos of tourist souvenirs that depict the large offer of these products in all touristic places in Serbia and in many smaller localities that have the pretension of becoming such.

2. SOUVENIRS AND TOURISM

The word *souvenir* originates from French, derived from the verb *se souvenir*, meaning "to remember." In its original sense, a souvenir is something that serves as a reminder—of a place, an experience, or a person. More broadly, it refers to a keepsake or memory. The Latin root *subvenire*—meaning "to come to mind" or "to assist"—also reflects this concept of evoking remembrance. The term has been adopted into many languages, including Serbian, with little alteration. Today, it generally refers to an item brought back from a trip or meaningful location, serving as a memento of that experience. Souvenirs are popular among tourists who purchase or receive them as gifts to commemorate a journey or a special moment. These objects often evoke memories of the trip itself, the person who gave the gift, or a significant experience during travel. Souvenirs are typically small and portable, making them easy to pack and carry. They are closely tied to specific tourist destinations and often depict local landmarks, cultural symbols, or traditional motifs. While their material value may be modest, they often carry deep sentimental significance—especially when given by friends or loved ones. The tradition of collecting souvenirs dates back to ancient times. In early civilizations such as Egypt, Mesopotamia, and those in Central and South America, as well as Ancient Greece and Rome, people would bring back sacred items or symbolic figures from pilgrimages and visits to temples. In Ancient Egypt, visitors to the pyramids would often take small pieces of stone as keepsakes. In Greece and Rome, souvenirs included items bearing the images of gods, heroes, or notable monuments. During the Middle Ages, souvenirs were primarily religious in nature. Pilgrims returning from holy sites often carried relics, crosses, or medallions believed to possess spiritual power, which they kept as protective charms. With the onset of maritime trade and global exploration in the modern era, souvenirs began to include exotic items such as feathers, spices, seashells, silk, and textiles brought from distant lands. In the 20th century, the rise of mass tourism transformed souvenirs into widely available commercial products—postcards, magnets, T-shirts, miniature replicas of famous landmarks, and more. Today, souvenirs are found everywhere—from museum gift shops and airports to local markets and online platforms. The production and exchange of souvenirs have fostered intercultural connections, contributing to globalization, economic growth, and career opportunities in creative and tourism-related industries. Understanding the cultural relevance and global role of souvenirs highlights the importance of adaptability and cultural awareness in tourism. These qualities are essential for developing global competence and advancing careers in an increasingly interconnected world.

3. TEXTILE SOUVENIRS

Textile souvenirs come in a variety of forms, functions, and styles, yet they all share a common feature: they represent a fusion of art, craftsmanship, and local tradition. Their diversity is influenced by geography, culture, and methods of production. Textile souvenirs are particularly popular due to their portability, practicality, and cultural significance. These are fabric-based items sold as keepsakes from travels or cultural events, often featuring local motifs, symbolic patterns, embroidery, or traditional designs. They range from wearable items such as T-shirts and blouses bearing the name of a city, region, or country, to handcrafted garments adorned with ethnic embroidery or folk patterns. Textile souvenirs may also include lace tablecloths, handbags, shopping totes, wallets, and traditional footwear like *opanci*. These products are typically created in an ethnic style, reflecting regional traditions and designs, and are intended for everyday use. Other forms of textile souvenirs include fabric dolls and children’s toys, towels, kitchen cloths, scarves, and caps featuring local symbols, national flags, names of tourist destinations, or traditional ornaments. They can be found at almost every tourist destination. What makes these souvenirs particularly valuable is their role in preserving and transmitting tradition through patterns, colors, and techniques. Many are handmade, supporting local artisans and connecting past and present by merging cultural heritage with contemporary design. These diverse textile items are more than just memorabilia—they act as cultural ambassadors, telling the story of a people, their values, and artistic heritage. Many of the techniques used in producing textile souvenirs are rooted in ancient customs. Embroidery has for centuries been used to decorate clothing, towels, and table linens. Rug weaving, such as the renowned *Pirot kilim*, is passed down through generations and is recognized as part of UNESCO’s intangible cultural heritage. Specific colors and patterns often indicate the region, social status, or even marital status of the person wearing the garment. By purchasing and using these souvenirs, tourists and locals alike contribute to the preservation of traditional crafts that might otherwise disappear. Textile souvenirs frequently incorporate elements of folk art—such as symmetrical patterns, stylized animals, plants, geometric shapes, and scenes from folklore. Creating these items requires skill, patience, and creativity. In modern practice, designers often collaborate with local artisans to blend traditional techniques with contemporary aesthetics, resulting in objects that are functional, visually appealing, and culturally meaningful. These textile creations can be used in everyday life, but also stand as artistic expressions. For tourists, they serve as a tangible connection to the places they’ve visited and a way to honor and promote local culture. When paired with modern fashion, textile souvenirs can even become a part of one’s personal identity. *Figure 1 shows traditional Serbian folk attire photographed on the Bridge of Love, located in Vrnjačka Banja, one of Serbia’s most well-known tourist destinations.*

Figure 1: Serbian Folk Costume

One of the most well-known textile souvenirs from Serbia is the Pirot kilim, which serves as both a tourist and textile symbol of the country. It is handmade using a knot-free weaving technique and is recognizable by its geometric patterns and vibrant colors. Each pattern carries symbolic meaning, often related to fertility, protection of the home, or nature. These kilims are used as floor coverings, wall decorations, or in smaller formats as decorative souvenirs. Serbia has a rich tradition of textile craftsmanship and handmade art, passed down through generations over the centuries. Textile souvenirs from Serbia are authentic, handcrafted items that reflect the nation's cultural heritage, folk customs, and distinctive national symbols.

Figure 2: Pirot Kilim

Textile souvenirs represent a unique blend of art, craftsmanship, and local tradition. In Serbia, they are not only popular tourist items but also important cultural artifacts that carry the legacy of centuries-old textile traditions. Each region in Serbia boasts distinctive embroidery patterns, weaving techniques, and color schemes, reflecting the diverse cultural landscape of the country. One of the most iconic textile souvenirs is the Pirot

kilim, a handwoven rug known for its vibrant colors and geometric motifs. Each pattern on the kilim holds symbolic meaning, often connected to fertility, protection, or nature. The Pirot kilim is recognized both as a tourist symbol and as an authentic expression of Serbian textile craftsmanship. Traditional embroidery plays a crucial role in Serbian textile heritage. Regions such as eastern Serbia, around Negotin, and southern Serbia, near Leskovac, are renowned for their distinctive floral and geometric embroidery used on garments and household textiles. These traditional motifs continue to inspire contemporary designs, bridging the gap between past and present. Additionally, handmade lace, such as the famous Pirot lace and lace from other regions, exemplifies the skill and artistry passed down through generations. Lace is widely used to adorn clothing and household items and has become a sought-after souvenir symbolizing elegance and craftsmanship. Serbian folk costumes also influence the design of textile souvenirs. Items such as vests, traditional footwear called *opanci*, scarves, and belts are frequently reproduced as souvenirs or integrated into ethnic fashion collections. These items serve as ambassadors of Serbian culture, enabling both tourists and locals to engage with and appreciate the country's rich heritge.

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Figure 3: Lace embroidery on traditional folk costume from Šumadija

In addition to traditional folk costumes, the Pirot kilim, embroidery, and lace, textile products that vividly represent the country or region where they are made are also very popular among tourists in Serbia. These are often items used to carry light belongings that can be worn daily and everywhere, such as decorative handbags and backpacks. They form part of the wardrobe that tourists purchase as an expression of their enjoyment of their stay in that place, but also as a way to display personal achievement through visiting various tourist destinations. Such items serve as a symbol of status and travel bragging rights, especially in areas where travel is less common**.** Figure 4 shows textile souvenirs – decorative textile handbags.

Figure 4: Textile handbags.

The term **benchmark** or **best practice** is commonly used in economics and management. Essentially, it represents a comparison of a social or natural category with the best in the same class. This involves observing certain textile souvenirs at tourism events and applying successful experiences with the aim of strengthening tourism potential, increasing visitor numbers, and consequently boosting tourism revenue. The following images show details of textile souvenirs from Serbia and neighboring countries.

Figure 5: Textile souvenirs in a souvenir shop in Kopaonik

Figure 6: Textile souvenirs at the Surva 2025 festival in Pernik, Bulgaria

Figure 7: Textile souvenirs at the square in Timișoara, Romania

Figure 8: Tourist attraction in Edirne, Turkey. Sale of textile souvenirs at the market

4. TEXTILE SOUVENIRS THROUGH THE PRISM OF THE 7P MARKETING MIX ELEMENTS

With the growth of tourism and globalization, textile souvenirs have experienced significant transformations in both their design and the methods of production and distribution. Contemporary trends present new challenges but also create opportunities to preserve tradition and foster creativity. Modern technologies enable fast and cost-effective mass production of textile souvenirs, including printed T-shirts, bags, and other tourist-themed items. However, mass production often compromises authenticity and quality. Conversely, handmade textile souvenirs remain symbols of superior quality, uniqueness, and cultural significance. Their production requires considerable time, effort, and craftsmanship, which justifies their higher price and increases their appeal among connoisseurs and enthusiasts of traditional crafts. Many countries, Serbia included, have established initiatives and programs to support artisans and masters of traditional textile techniques. Tourism organizations frequently promote handmade souvenirs as integral components of a destination's cultural identity. The marketing mix concept, particularly the 7P model, is essential in-service sectors like tourism. It comprises seven fundamental elements necessary for effective product positioning and market penetration: Product, Price, Place, Promotion, People, Process, and Physical Evidence. Evaluating textile souvenirs through the lens of these elements provides valuable insights into how these authentic products can be successfully marketed while safeguarding their cultural heritage. Textile souvenirs represent products that blend tradition, art, and cultural identity. Their authenticity, craftsmanship quality, and symbolic motifs make them particularly appealing to consumers. Whether it is handwoven kilims, embroidered folk costumes, or contemporary fashion items inspired by traditional designs, these products must meet both aesthetic and emotional expectations of buyers seeking to bring home a tangible piece of culture. Pricing depends on the complexity of production, materials used, and level of authenticity. Handmade items typically command a premium due to the skill and time invested, whereas mass-produced souvenirs tend to be more affordable. Setting the right price is crucial to balance competitiveness with sustainable production practices. The place of sale plays a pivotal role in the accessibility and visibility of textile souvenirs. Ideal venues include tourist hotspots, specialty souvenir shops, fairs, ethnographic villages, and online platforms. Presence in locations frequented by tourists significantly enhances sales potential. Promotion encompasses all activities aimed at informing and motivating prospective customers. For textile souvenirs, effective promotion involves storytelling about the origin, symbolism, and traditional craftsmanship behind the products. This can be achieved through social media, tourist guides, craft fairs, and cultural events. Demonstrations of the production process and involvement of artisans in promotional activities further reinforce product authenticity. People are the cornerstone of successful sales — artisans crafting the souvenirs, sales personnel, and tourist guides who narrate the products' stories. Their expertise, enthusiasm, and engagement profoundly impact customer experience and elevate the perceived value of the souvenirs. The production and distribution process encompasses traditional techniques, quality assurance, and

presentation strategies. A transparent, well-managed process ensures authenticity and quality, fostering consumer trust. Physical evidence refers to packaging, labeling that provides origin and authenticity information, and the aesthetic appeal of the point of sale. Attractive, culturally resonant packaging, certificates, and authenticity seals enhance consumer confidence and emphasize the souvenirs' cultural significance. By harmonizing these elements of the marketing mix, producers and retailers can effectively position textile souvenirs in the market, preserving cultural heritage while promoting sustainable craftsmanship. Implementing the 7P marketing mix framework offers a comprehensive approach for positioning textile souvenirs, optimizing their market presence, and maximizing their appeal and value to consumers.

5. STATISTICAL RESEARCH

The primary method for data collection in this study was a survey questionnaire. During the questionnaire design, special attention was paid to the clarity and comprehensibility of the questions for a broad audience. A total of 100 respondents participated and answered the questions. Regarding the sampling method, a random sample was used in the research. The following tables and charts present the results and provide an interpretation of the survey findings.

In response to the question, "Do you travel frequently?" 73% of respondents answered YES, while 27% answered NO. Chart 1 illustrates the distribution of answers to this question in relative terms.

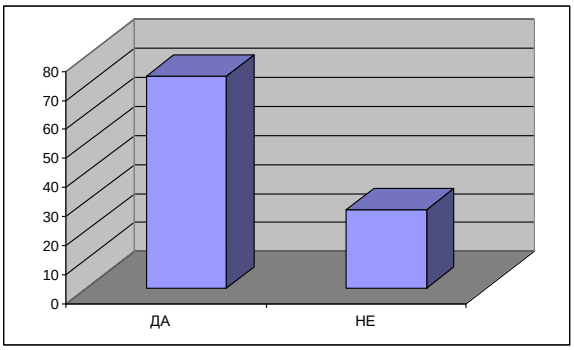

Chart 1: Response to the question: Do you travel frequently?

To the next question, "Do you buy textile souvenirs?" 55% of respondents answered YES, while 45% answered NO. Chart 2 shows the distribution of responses to this question in relative values.

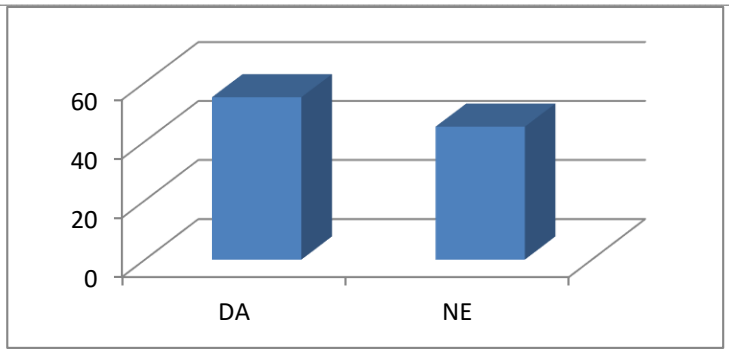

Chart 2: Response to the question: Do you buy textile souvenirs?

To the question, "Do you believe that textile souvenirs play a significant role in the development of tourism in Serbia?" only 12% of respondents answered NO, while 88% answered YES. Chart 3 presents the distribution of responses to this question in relative terms.

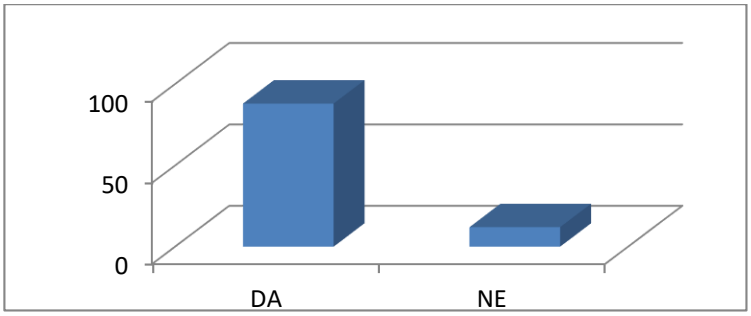

Chart 3: Response to the question: Do you believe that textile souvenirs play a significant role in the development of tourism in Serbia?

6. CONCLUSION

The primary objective of this study was to address the hypothesis: “Is there a correlation between textile souvenirs and tourism development in Serbia?” Based on the data collected through the survey and a thorough review of relevant literature, it can be confidently stated that a strong connection exists between these two phenomena. Notably, 88% of respondents affirmed the significance of textile souvenirs in tourism development. Furthermore, approximately half of the participants reported that they frequently purchase textile souvenirs. Serbia boasts a rich tradition of producing textile clothing and decorative items, which serve as important tourist attractions and are highly sought after by visitors as mementos of their travels. Particularly noteworthy are the Serbian national costumes and the Pirot kilim, which is inscribed on UNESCO’s Intangible Cultural Heritage list. This positive trend and the preservation of these cultural treasures should be effectively harnessed. One strategic approach to this end is to enhance the visibility of textile

souvenirs through increased participation in tourist events, festivals, and trade fairs. It is important to emphasize that organizing such events yields considerable economic and tourism benefits. Frequent exposure, combined with the presentation of textile souvenirs and cultural craftsmanship, along with effective marketing strategies employing the seven fundamental elements of the marketing mix, contributes to greater tourist influx and increased revenue generation within the tourism sector.

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RESEARCH OF LABELING STANDARDS ON TEXTILE PRODUCTS

Professional paper
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ABSTRACT: *All textile products must meet certain needs and standards. It is evident that textiles are best recognized in the fashion industry, where the fineness of the material is expressed, qualitatively assessed with the implementation of certain standards for storage, ironing, maintenance, longer use and possible recycling. Among the characteristics that are important for clothing items, the use of bleach, washing at a certain temperature, hand or machine washing, ironing, separation of clothing according to raw material composition (cotton, wool, textiles, elastane), washing duration, drying, and the like are highlighted. This paper presents existing standards for labeling textile items, which exist in different parts of the world. The purpose of familiarizing yourself with the lists of standards is to provide a basis for the standardization of environmentally sustainable materials, which will use resources rationally, with innovative proposals understandable to all manufacturers, distributors, verifiers, sellers, users and re-users of the observed textile goods.*

Keywords*: standards, label, textile, categories.*

ISPITIVANJE STANDARDA ZA OZNAČAVANJE NA TEKSTILNIM PROIZVODIMA

APSTRAKT: *Svi tekstilni proizvodi moraju da zadovolje neke potrebe i standarde. Evidentno je da se tekstilstvo najbolje prepoznaje u modnoj industriji, pri čemu do izražaja dolazi finoća materijala, kvalitativno procenjena uz proštovanje određenih standarda za čuvanje, peglanje, održavanje, duže korišćenje i moguću reciklažu. Od karakteristika koje su bitne za odevne predmete izdvajaju se upotreba izbeljivača, pranje na određenoj temperaturi, ručno ili mašinsko pranje, peglanje, izdvajanje odeće prema sirovinskom sastavu (pamuk, vuna, tekstil, elastin), dužina trajanja pranja, sušenje i slično.*
U ovom radu se prilažu postojeći standardi kod označavanja tekstilnih predmeta, koji postoje u različitim delovima sveta. Svrha upoznavanja sa listama standarda je osnov za ujednačavanje ekološki održivih materijala, koji će koristiti resurse racionalno, uz

inovativne predloge razumljive svim proizvođačima, distributerima, proverivačima, prodavcima, korisnicima i ponovnim korisnicima posmatrane tekstilne robe.

Ključne reči: *standardi, etikete, tekstil, kategorije.*

1. INTRODUCTION

There are various standards in the world, which differ more or less in relation to others according to the degree of concretization, established specific requirements for the fulfillment of application standards. In the textile industry, well-known brands are synonymous with the Western culture of the clothing industry, while the abundance of clothing is consequently associated with cultures that have a large population, and refinement and quality with Italian or French fashion. The goal is to have unique standards, which will be applied everywhere and thus familiarize consumers with the rules of clothing maintenance, treatment with different chemical means, without rapid rejection.
The European Union has specific labeling systems for textile products. In order for textile products to be found on its market, they must have a label that determines the composition of the textile fibers used, as well as indicating those that are not, but are, for example, of animal origin. National authorities can check the conformity of textile products with the information shown on the label at any stage of the marketing chain, such as: at the time of application for customs clearance, in the warehouses of distributors, in wholesale or retail establishments. The label must explain the composition of the fabric - written in descending percentage order, use clear and legible text, including uniform writing (same font, size and style), contain a clear separation between information on the composition of the textile and other information, such as product care.
The rules on the labeling of textile products in accordance with the current Textile Labeling Regulation are limited to the fiber composition of textile products, which has increasingly enabled the introduction of different labeling requirements in EU countries. Physical labels are currently envisaged, while digital labeling technologies are affordable. The EU Ecolabel helps consumers, retailers and businesses make sustainable choices. In general, textile products must have a permanent, legible, easily visible and accessible label, either on the product or on its packaging.

2. STANDARDS IN TEXTILE

In general, without information on size and care instructions, it is possible that neither consumers nor distributors would purchase the product. Therefore, it is recommended to add such information. It would also increase the risk of returns, should the garment be washed at the wrong temperature. It should be noted that there are voluntary standards:

- EN 13402, which covers clothing size marking; and
- ISO 3758, which covers the labeling of textile care.

The International Organization for Standardization (ISO) has set standards for three types of environmental labels:

I) ISO 14024 – Third party certifications,
II) II) ISO 14021 - Independent environmental claims,
III) III) ISO 14025 - Declarations on ecological products

ISO 3759:2011 specifies a method for preparing, marking and measuring textile fabrics, garments and fabric assemblies for use in tests to assess dimensional change after a specific treatment, e.g. washing, dry cleaning, soaking in water and steaming, following the procedures in ISO 3005, ISO 7771, ISO 6330, ISO 3175 or ISO 15797. ISO 3759:2011 applies to woven and knitted fabrics and finished textile products. Procedures do not apply to certain upholstery covers.

The **General Product Safety Regulation** (GPSR) covers consumer products and mandates that "only" safe products can be placed on the EU market. Unsafe products may contain flammable materials, pose a choking hazard, or have small parts that detach easily. There are several harmonized standards relevant to textile products:

- EN 14682 - Safety of children's clothing, Strings and laces on children's clothing.
- EN 13209-1 - Child care products, Carriers with a back frame
- EN 13209-2 - Products for the use and care of children, Soft carrier

When there are no harmonized standards for a specific product, you can still use the relevant national, international or non-harmonised EN standards to assess the safety of the product.

The **Global Organic Textile Standard** (GOTS) was developed by leading standard setters to define globally recognized requirements for organic textiles. From the collection of raw materials, ecologically and socially responsible production to labeling, textiles certified according to the GOTS standard provide the consumer with a credible guarantee.

The **Fair-trade Textile Standard** incorporates an innovative approach to assurance to address weaknesses in the compliance audit model for the textile industry, which includes: 1) improving auditor competencies, including fraud identification, 2) strengthening worker participation in the process, 3) identifying the root cause of non-conformities so that they can be addressed, especially when related to the purchasing practices of brand owners, 4) maintaining a high level of control over the frequency and duration of audits, including unannounced audits, 5) increased transparency throughout the process.

Only fibers guaranteed by Fairtrade approved schemes can be used in processing under the terms of the Fairtrade Textile Standard. Schemes are classified into environmental, socioeconomic criteria and scheme management system. A certain threshold in a category, or combination of categories, must be met for the scheme to be used within the Textile Standard, where child and forced labor is not allowed.

OEKO-TEX® STANDARD 100 is a label for textiles tested for harmful substances. Every article, from the yarn to the finished product, that bears the STANDARD 100 mark has received a certificate of passing safety tests for the presence of harmful substances.

ASTM Textile Standards provide specifications for the physical, mechanical, and chemical properties of textiles, fabrics, and fabrics, as well as natural and man-made fibers. Textiles covered by these standards are usually formed by weaving, knitting or spinning fibers such as glass fiber threads, wool and other animal fibers, cotton and other

plant fibers, yarn, sewing thread. These textile standards assist fabric designers and manufacturers in testing textiles to ensure acceptable characteristics for proper end use.
The **global standard for organic textiles ECO Textile - ECOmark®** is the world's leading standard for the processing of textile products made from organic fibers. It defines high-level environmental criteria throughout the organic textile supply chain and requires compliance with social criteria.
ECOmark is a worldwide, independent, independent testing and certification system for auxiliary materials used for raw, semi-finished and finished textile products at all levels of the process. Examples of certified items: raw and dyed/finished yarns, woven and knitted fabrics, accessories such as buttons, zippers, sewing threads or labels, various types of finished goods (all types of clothing, housewares and household items), textiles, bedding, towel products and more).

3. MARKING AND LABELS ON TEXTILE

Labeling is the most effective way to connect with the consumer by which he learns the characteristics of the product, reads the instructions and can preserve the product. More and more information is put on labels to attract customers. Labeling of textiles aims to familiarize consumers with the item, to see the impact of the purchase decision based on true facts that provide certain certainty regarding the quality, origin, method of production and materials used in the purchased item of clothing.
All items must have a fiber content label, either on the item or on the packaging. This label does not need to be permanently attached to the garment and can be removed. If the product is delivered to a wholesaler, the label may be included in the business documents (eg invoice). Member States may require that their national language be used for labeling and marking required by the Directive.
Consumers must be sure that a textile item is safe for use and meets the required standards. There is a law that protects the rights of consumers. The British Standards Institute (BSI) tests products and the process by which they are manufactured. If the product meets the required standards, the manufacturer can display the BSI Kitemark on the product label. Consumers trust that products bearing the Kitemark have undergone a rigorous certification process and will be not only safe to use, but also fit for purpose for which they were designed.
There are data that are not mandatory, but contribute to preserve the properties of the product: washing method (wet or dry, hand or machine, etc.), which products can be used and which cannot, whether ironing or drying is allowed. The symbology used corresponds to ISO (International Organization for Standardization), with 5 internationally recognized symbols: Wet cleaning; Dry cleaning; Product; Drying; and Ironing. Attention should be paid to the order and use of the pictograms in Figure 1.

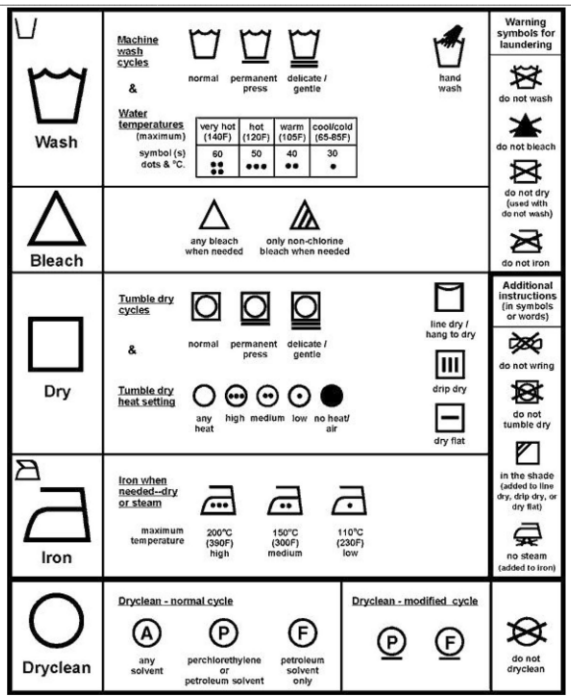

Figure 1: Sequence of pictograms [Ginetex, 2015]

4. INTERNATIONAL STANDARDS OF MARKING ON TEXTILE

European Union member countries. According to EU Regulation No. 1007/2011 of the European Parliament and the Council, textile products are considered to be products that have at least 80% by weight of textile fibers, products for covering furniture, for umbrellas and sunshades with at least 80%; textile components (upper part of multi-layer floor coverings, mattress, camping equipment); textile products that are part of other products and form an integral part that is listed. Only textile products composed of the same fiber can be labeled "100%, pure or whole". There are 50 textile fibers on the EU list including wool, cashmere, horse hair, cow hair, silk, cotton, linen, natural hemp, jute, coconut, broom, acetate, alginate, viscose, acrylic, polyamide or nylon, polyester and others.

4.1 National labeling standards

Australia. Textile care labeling in Australia and New Zealand is established for the supply of new clothing and textiles. The mandatory standard for clothing and textile products is based on standard AS/NZS 1957:1998, which was amended by a consumer protection notice in 2010 (Australian Competition & Consumer Commission). Clothing and textile care labeling information can be found on the Australian Clothing Safety website, so whether it is wholly or partly manufactured in Australia, imported or exported affects. There used to be size standards for women's clothing AS 1344-1997 (underwear,

outerwear and carpets), men's clothing AS 1954-1976 (multi-cut outerwear and industrial clothing) and children's and infants' clothing AS1182-1997 (underwear and outerwear), all of which now fall under EN 13402 (the European standard for sizing clothes).

India. An Indian Standard was adopted at the Bureau of Indian Standards following a proposal by the handloom fiber section. Consumers are interested in information related to various textile requirements, such as blend composition, length, width, mass (g/m2), color fastness, fire resistance, shrinkage and care instructions, so that they can optimally use the textile and get full value for the price they paid. All important information should be marked on the textile in order to fulfill the interests of consumers, and thus abuse in the textile trade related to false markings that mislead consumers can be suppressed.

The height of letters on labels must be a minimum of 5 mm for signs, and for all other letters, the minimum height must be 2 mm. A fabric or finished garment may be marked with a standard mark (BIS) and the use of the standard mark is governed by the provisions of the Bureau of Indian Standards Act, 1986.

China. China's national standard is considered an important milestone to conquer the market, which has the mark "GB" is an abbreviation of the Chinese Pinyin "Guo Biao". A few different Chinese Standard Code prefixes are:

• GB - National Standard – Mandatory
• GB/T - National Standard - Recommended ("/T" stands for Recommended Standard)
• FZ/T - Abbreviation of "Fang Zhi", ie. textile industry standard – Recommended
• QB/T - Abbreviation of "Qinggong Biaozhun", ie. light industry standard (applies to some leather goods, footwear, hard goods, etc.) – Recommended

The mandatory standard in China refers to human health, safety and hygiene or to the category of high-risk products. A voluntary standard does not mean that the brand owner/importer/trader can ignore the requirements of the voluntary standard, but one must be chosen which when stated as an "enforceable standard", all the requirements of the standard must be met. Mandatory standards apply to textiles or clothing, because what people wear is considered important. In China, the size designation is based on the Chinese size standard, without S, M, L or 32, 34. For example, for adult clothing, the Chinese size is formed by using body height, chest or waist, and body type code. Several size standards are available, e.g. men's, women's, children's, sweater, etc.

Serbia. In 2013, the Ministry of Economy accepted European directives into the legal system of the Republic of Serbia for marking textile products and footwear. The Ministry of Economy - Sector for Quality and Product Safety is responsible for the transposition and implementation of European Regulation (EU) 1007/11 and Regulation (EU) 2018/122. This area is regulated by the Rulebook on Labeling and Marking of Textile Products ("Official Gazette of RS", No. 86/2019 - hereinafter: Rulebook) which is in accordance with all principles and essential requirements of Regulation No. 2018/122 of October 20, 2017 of the European Commission amending Regulation no. 1007/11 of the European Parliament and the Council on the names of textile fibers and the labeling and marking of the composition of textile products.

Spain. The Royal Spanish Academy (RAE) defines marking as a "label", as a piece of paper, rectangular in shape, that is placed on an object for its identification. Labeling of textiles has the purpose of protecting both consumers and workers, in order to obtain from them information on ethical and environmental considerations. Few authors analyze the scenario found in textile labeling in relation to a certain geographical area (Boström et al. 2005; Stolle and Micheletti 2013), while Austgulen (2016) points out that textiles and clothing are particularly important because they are considered one of the most polluting industries. In Spain, the labeling of textiles is regulated in Royal Decree 928/1987, where, apart from the place of installation, there are positive provisions for the obligation to have a label and a negative one indicating textile products that are exempt from labelling. Textile products must be labeled but it is limited to those who produce, commercialize or distribute textile products in the Spanish market (Santos-Roldan et al., 2020).
Turkey. The rules on labeling and marking of textile products specified in the Turkish system are in accordance with Regulation (EU) no. 1007/2011 of the European Parliament and the Council in 2011 on the names of textile fibers and related labeling and marking of fiber composition of textile products. Products must be labeled in a permanent, easily legible, visible and accessible manner to indicate their fiber composition in accordance with the Regulation. Manufacturers must ensure that textile products are properly labeled or marked with an indication of their fiber composition. Distributors must ensure that textile products bear appropriate labels, without confusing products with fiber names. Manufacturers are responsible for ensuring that the label is legible, firmly attached and accessible and not misleading. When it is impossible to determine the manufacturer, the seller is responsible for providing appropriate labeling.

5. CONCLUSION

Textile products are important technologically processed semi-finished products and raw materials, which together with textile fibers create products used in the clothing industry, agriculture, military and construction sectors.
Environmental problems such as global climate change, harmful residues, toxic chemicals, the ozone hole, acid rain, water and air pollution, which are increasingly felt in the environment today, are caused by the textile industry, along with other industries. During production, there is a large consumption of water, and some chemicals are also used, which creates various wastes, and the production of environmentally friendly textiles is imposed. In addition, the eco-labeling system was conceived as a solution to prevent air and water pollution.
The European Union is an important market for Serbia's exports, and as a result of increasing environmental awareness, the countries of the Union attach importance to the production of products that do not harm human health and nature. For this purpose, the eco-label system has been applied for almost twenty years and covers a large number of products. Many standards have been developed according to the ecological principle, as well as socioeconomic and integrative, while each country can define its own specifics by which it determines the stages or prerequisites for obtaining the mark.

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THE INFLUENCE OF QUALITY MANAGEMENT AND INTELLECTUAL CAPITAL MANAGEMENT ON SUSTAINABLE BUSINESS IN FASHION COMPANIES

Professional paper
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ABSTRACT: *The changing global market, along with modern management methods implemented through organizational structuring, requires flexibility and adaptability from fashion companies. These companies face increasing demands for sustainable business practices. In countries in transition, such as ours, fashion companies can respond to user demands and meet their growing needs in terms of design and technology, thereby gaining a competitive advantage. This paper analyzes the impact of modern management methods on the competitiveness and sustainability of fashion companies in our country. In addition to numerous factors influencing sustainable business, market performance, and competitiveness, the paper examines the effects of quality management and intellectual capital management. The results can help fashion companies in Serbia - where maintaining adequate quality and preventing intellectual capital fluctuation remain significant challenges - to monitor and adapt to the factors and methods influencing competitiveness and sustainable business in today's globalized business environment.*

Keywords: *fashion industry, sustainable business, quality management, intellectual capital management.*

UTICAJ MENADŽMENTA KVALITETOM I MENADŽMENTA INTELEKTUALNOG KAPITALA NA ODRŽIVO POSLOVANJE U MODNIM KOMPANIJAMA

APSTRAKT: *Promenljivo globalno tržište, kao i nove savremene metode upravljanja kroz izgradnju organizacione strukture zahtevaju od modnih kompanija fleksibilnost i prilagodljivost. Pred modne kompanije postavlja se zahtev za održivim poslovanjem, gde zemalje u tranziciji, kao što je i naša mogu da prate zahteve korisnika, odgovore na njihove sve veće potrebe u okviru dizajna i tehnologije i tako omoguće konkurentsku*

prednost. U radu se analizira uticaj savremenih metoda upravljanja modnih kompanija u našoj zemlji na konkurentnost i održivo poslovanje. Analizira se pored mnogobrojnih faktora koji utiču na održivo poslovanje, tržišne performanse i konkurentnost, uticaj menadžmenta kvalitetom, i upravljanja intelektualnim kapitalom. Rezultati omogućavaju modnim kompanijama u Srbiji, gde je veliki problem postići odgovarajući kvalitet sprečiti fluktuaciju intelektualnog kapitala, da prate i prilagode uticaj faktora i metoda koje utiču na konkurentnost i održivo poslovanje u globalizovanom poslovnom svetu.

Ključne reči: *modna inustrija, održivo poslovanje, upravljanje kvalitetom, upravljanje intelektualnim kapitalom.*

1. INTRODUCTION

Today's fashion industry faces numerous challenges related to competition, environmental pressures, and shifts in consumer habits. The modern trend as an imperative calls for high-quality and sustainable products, while companies simultaneously strive to preserve creativity and innovation. Modern business is characterized by rapid and widespread changes, requiring organizations to adopt new tools and methods to improve their efficiency. Success is achieved only by those organizations that are ready to continuously apply techniques and methods aimed at constant improvement, development, and the generation of new ideas about the roles and activities of organizations in order to maintain a competitive advantage. Continuing to operate with an outdated business model can be highly damaging for companies [1]. This is especially true for fashion companies, where trends change rapidly and consumers are becoming increasingly demanding in terms of design, quality, and price. In this context, alongside numerous other business factors, two key concepts stand out for achieving sustainable business practices: quality management and intellectual capital management. Their implementation significantly enables fashion companies to respond to market demands, reduce their negative environmental impact, and create long-term competitive advantages [2].

It is necessary for organizations to refine their strategies not only to generate profit but also to achieve long-term sustainability. Achieving competitiveness is challenging and requires effective management, including improvements in various business areas such as distribution, logistics, production, and quality. Modern techniques, tools, and management methods are essential for creating a successful, market-competitive organization and ensuring sustainable market performance. The implementation of management systems based on methods and concepts such as Kaizen, 5S, Six Sigma, TQM, Just-in-Time, and Lean Manufacturing has been validated by the successes of companies that apply these systems [3,4].

In more developed economies, where management systems are often well established, Serbian companies face challenges such as limited access to advanced technologies, an evolving regulatory framework, and the need to adapt to rapid changes in the global market. While environmental and social sustainability are often discussed in the broader

context of contemporary management and corporate responsibility, specific modeling and research tend to focus on how management practices contribute to economic sustainability within companies. Sustainable business practices and competitiveness are essential for survival in a competitive environment [5].

2. QUALITY MANAGEMENT IN THE FASHION INDUSTRY

Quality management (QM) in fashion companies plays a key role in fostering sustainable development, both within organizations and in the broader socio-economic environment. Quality does not refer solely to the aesthetic component and durability of fashion products, but also to responsible behavior toward human resources and environmental protection. In the context of sustainability, organizations must adopt a holistic approach to quality management, one that encompasses environmental, social, and economic dimensions to ensure not only business excellence but also the long-term sustainability of their operations [6].

To achieve business excellence and sustainability, organizations must address all aspects of quality, including product quality, process efficiency, environmental responsibility, and social equity. By applying the principles of Total Quality Management (TQM), companies can improve all phases of their business. Quality control along the supply chain prevents the occurrence of defective products and reduces waste, thus contributing to the conservation of resources and the reduction of CO_2 emissions.

One of the most significant opportunities to contribute to sustainable development is the integration of quality management knowledge and practices. From a micro perspective, the relationship between quality management and sustainability can be seen within organizational processes, where resources are transformed into value for customers. Research has shown that the implementation of TQM programs, which emphasize continuous improvement and the active involvement of employees at all levels, has a positive impact on corporate sustainability. By incorporating TQM into their operations, organizations not only improve their overall quality performance but also contribute to broader sustainable development goals, such as reducing environmental impact and increasing social responsibility.

QM philosophies, methods, and tools such as Six Sigma, Lean Manufacturing, and continuous improvement methodologies are essential for creating value and promoting sustainability within an organization. Focusing on quality increases consumer satisfaction and loyalty, as customers increasingly seek fashion products that last longer and have a lower environmental impact. In this way, product quality directly supports sustainable business models such as the capsule wardrobe, slow fashion, or recycling [7].

3. INTELLECTUAL CAPITAL MANAGEMENT IN THE FASHION INDUSTRY

Market conditions have become more competitive than in previous periods. A competitive company at all levels requires employees equipped with the skills to drive innovation, manage risk, transform economic systems, and achieve social goals within the framework of sustainability. In fashion companies, intellectual capital as an intangible asset includes

employees' knowledge, designers' creativity, the ability to follow fashion innovations, brand management, and customer relationships.
Intellectual capital in the fashion industry is extremely important because competitive advantage depends on creative ideas and brand reputation, representing a key point of differentiation in the fashion market.
Intellectual capital management in fashion companies involves:

-Resource mapping: systematic recording and assessment of creative potential
-Intellectual property protection: through trademarks, industrial designs, and patents
-Human capital development: continuous training, and fostering innovative and digital competencies
-Commercialization**:** through licensing, co-branding, and digital platforms [8]

Through digitization processes, intellectual capital management in the fashion industry increasingly uses artificial intelligence, blockchain technology, and digital factories as new tools for sustainable business and competitive advantage.
World-renowned brands build their reputation on sustainability and innovation, and are perceived as ethically responsible, thereby enhancing their reputation and customer loyalty, which leads to better market results. Brands such as Gucci and Balenciaga invest heavily in protecting their designs and developing digital communications with customers, thus safeguarding and developing their intellectual capital. Meanwhile, Zara relies on agile design teams and advanced digital tools to monitor consumer trends, successfully transforming creative capital into rapid production [9,10].

4. METHODS

The research was conducted through a structured survey of managers of small and medium-sized fashion enterprises in Serbia. The collected data were analyzed using descriptive statistics to summarize and describe the key characteristics of the sample, providing a basis for more advanced analyses. Correlation analysis was applied to examine relationships between different variables, linear regression was used to predict outcomes based on one or more independent variables, while logistic regression was employed to model binary or categorical outcomes. The survey results were analyzed using a range of statistical procedures and methods. Basic descriptive statistical methods were used to summarize and describe the collected data. Categorical variables were analyzed through their frequencies and percentage shares, while numerical variables were described using measures such as means, standard deviations, minimum, and maximum values.
As part of the research, an analysis was conducted to assess observed dimensions of organizational performance. These dimensions included quality management, human resource management, intellectual capital management, management methods, and market performance. Each of these dimensions was evaluated through a set of questions rated on a 1–7 Likert scale. For each dimension, the mean value of all responses was calculated, resulting in measurable variables that represent specific organizational factors. These variables were then used for further analysis and comparison, enabling a detailed quantitative assessment of organizational performance.

Quality Management (QM) received the highest mean score of 6.03, indicating that respondents assessed this area most positively. Such a high rating suggests that fashion companies are increasingly incorporating sustainable development principles into their quality management strategies. QM provides processes and standards for environmentally friendly production and high product durability. In contrast, Intellectual Capital Management (ICM) obtained the lowest mean score, indicating that respondents perceive this area as having the greatest potential for improvement. The mean value of 5.47 for ICM reflects a solid yet comparatively lower level relative to QM, which may imply that fashion companies still lack systematic investment in developing employees' knowledge, skills, and creative capacities to support sustainable business practices. ICM enables innovation, new materials, sustainable design concepts, and competitive advantage through knowledge and creativity. The relatively low standard deviations (ranging from 0.85 to 1.22) demonstrate a high degree of consistency among respondents' answers. The greatest variability was observed in Modern Management Methods (1.22), suggesting more diverse opinions regarding this dimension. All factors showed exceptionally high Cronbach's alpha values (>0.9), indicating very high internal consistency of the measurement scales. The maximum value for all dimensions was 7, while the minimum values varied but remained above 2, suggesting that none of the dimensions was rated extremely low.

Table 1: Descriptive statistics [4]

Dimension/ Factor	Mean (μ)	Standard Deviation (σ)	Min	Max	Cronbach's Alpha
Quality Management (MQ)	6.03	0.85	2.57	7.00	0.922
Human Resource Management (HRM)	5.69	1.00	2.13	7.00	0.914
Intellectual Capital Management (ICM)	5.47	1.05	2.25	7.00	0.901
Modern Management Methods (MMM)	5.61	1.22	2.00	7.00	0.955
Market Performance (MP)	5.75	0.88	2.56	7.00	0.941

5. CONCLUSION

The combination of quality management and intellectual capital management provides a strong foundation for sustainable business in fashion companies.

The synergistic effect of these two concepts enables greater awareness among managers and employees about modern business practices, reduces negative environmental impacts, increases competitiveness, improves customer relationships, enhances resource management, and boosts profitability.

In order to improve the sustainability of market performance at the national level, the fashion industry should integrate quality management and intellectual capital management into its strategic goals under modern market conditions, as these elements are crucial for the future.

By improving product quality, responsibly managing supply chains, and fostering innovation based on knowledge and reputation, the fashion industry - through an integrated approach to these managerial practices - can ensure sustainable business

operations and achieve a stable competitive advantage, while consistently maintaining a focus on environmental protection and social responsibility.

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SESSION IV

ECOLOGY AND SUSTAINABLE DEVELOPMENT

8. Međunarodna naučna konferencija
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ENVIRONMENTAL CHALLENGES AND SUSTAINABLE APPROACHES IN THE TEXTILE INDUSTRY

Original scientific paper
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ABSTRACT: *The textile industry is one of the largest environmental polluters, with a significant impact on water consumption and waste generation. This paper analyzes sustainable approaches in the textile industry, with a particular focus on the use of environmentally friendly materials and the introduction of circular economy principles. Additionally, examples of best practices from the industry, modern technological innovations, and international standards that enable the transition to sustainable production and consumption models are presented. It is concluded that sustainability in the textile industry requires a systemic approach involving producers, consumers, and policymakers. For the complete realization of responsible business practices, broader collaboration between the industry, regulators, and consumers is essential in this transformation process. This paper can serve as a guide for companies in the textile sector on how to improve and advance their existing operations towards a responsible and sustainable business model.*

Keywords: *Textile industry, sustainable development, circular economy, ecological materials, ethical standards.*

EKOLOŠKI IZAZOVI I ODRŽIVI PRISTUPI U TEKSTILNOJ INDUSTRIJI

***APSTRACT**: Tekstilna industrija je jedan od najvećih zagađivača životne sredine, sa značajnim uticajem na potrošnju vode i stvaranje otpada. Ovaj rad analizira održive pristupe u tekstilnoj industriji, sa posebnim fokusom na upotrebu ekološki prihvatljivih materijala i uvođenje principa cirkularne ekonomije. Dodatno su predstavljeni primeri dobre prakse iz industrije, savremene tehnološke inovacije i međunarodni etički standardi koji omogućavaju prelazak na održive modele proizvodnje i potrošnje. Zaključuje se da održivost u tekstilnoj industriji zahteva sistemski pristup koji uključuje proizvođače, potrošače i zakonodavce. Za potpunu realizaciju odgovornog poslovanja neophodna je šira saradnja između industrije, regulatora i potrošača u ovom procesu transformacije. Ovaj rad može poslužiti kompanijama u tekstilnom sektoru industrije kao primer kako unaprediti postojeće poslovanje ka odgovornom i održivom načinu poslovanja.*

***Ključne reči:** tekstilna industrija, održivi razvoj, cirkularna ekonomija, ekološki materijali, etički standardi.*

1. INTRODUCTION

The textile industry is one of the largest sectors of the global economy, with a wide-reaching impact on production, trade, and employment. However, this sector is also one of the biggest polluters in the world, responsible for significant natural resource consumption and waste generation. According to United Nations data, the textile industry accounts for about 10% of global carbon dioxide emissions, and it is estimated that approximately 92 million tons of textile waste are discarded annually [1]. In light of these circumstances, the environmental challenges facing this industry are increasing, and the need for sustainable approaches in production and business is critical for reducing its negative impact on the environment.

Sustainable approaches in the textile industry encompass various strategies such as the use of recycled materials, ethically produced fabrics, the implementation of circular business models, and the optimization of production lines to reduce carbon dioxide emissions and water consumption. Additionally, ethical standards and fair trade play a significant role in ensuring fair working conditions and mitigating the ecological and social negative effects [2].

This paper explores the key environmental challenges faced by the textile industry as well as sustainable approaches that can help reduce its negative impact. Furthermore, it analyzes the role of innovation in production technologies and the importance of corporate social responsibility within sustainable business models. Understanding these approaches not only helps identify challenges but also provides concrete solutions that can contribute to the transformation of the industry towards more environmentally friendly and ethical business practices.

2. USE OF RECYCLED MATERIALS AND ETHICALLY PRODUCED FABRICS

One of the main challenges in the textile industry is reducing the consumption of natural resources and minimizing waste. The use of recycled materials is becoming crucial in achieving sustainable production chains [3]. Recycled polyester, for example, can be produced from old plastic bottles or textile waste, significantly reducing the need for new synthetic fibers and contributing to reduced pollution. Similarly, recycled cotton and wool are becoming popular in fabric production, reducing the need for new raw materials, which in turn decreases CO_2 emissions and water consumption.
Alongside the use of recycled materials, ethically produced fabrics, such as organic cotton, are becoming preferred choices. Organic cotton is grown without the use of synthetic pesticides and chemicals [4], thereby reducing the negative impact on the ecosystem. Furthermore, the production of organic cotton often involves respecting workers' rights and using environmentally friendly practices. This approach not only reduces negative ecological effects but also improves the social conditions of agricultural workers.
Use of organic cotton, hemp, recycled fibers, and biodegradable materials such as Mylo™ and Tencel™ is increasingly favored [5]. Avoidance of synthetic fibers derived from fossil fuels, such as polyester, helps reduce microplastic pollution and non-biodegradable waste [1].

3. RECYCLING AND CIRCULAR ECONOMY

The circular economy represents a sustainable business model based on reuse, recycling, and extending the lifespan of products. In the textile industry, this means creating products that can be recycled, refurbished, or reused, reducing the need for constant intake of new raw materials. Such models not only minimize waste but also reduce the overall ecological footprint of the industry.
One example of a circular model is focusing on design that allows products to be easily disassembled into their core components that can be reused. Companies implementing circular approaches often offer repair, recycling, or even product return services from end-users to avoid textile waste from going to landfills. This model, along with consumer education, can contribute to reducing textile waste and promoting sustainability throughout the entire production chain. Reusing textile waste in new products, designing for recyclability and durability, and applying circular economy principles throughout the supply chain help minimize landfill waste and extend product lifecycles [6].

4. SUSTAINABLE PRODUCTION TECHNOLOGIES

Manufacturing processes often involve large amounts of energy, water, and chemicals, and CO_2 emissions and water pollution are serious issues. Innovations in manufacturing techniques, such as using solar panels, energy-efficient machines, and wastewater recycling, can dramatically reduce the industry’s environmental impact.
One significant step is reducing water consumption in the production of cotton and other textile fibers. Innovative approaches, such as water recycling technologies and minimizing the amount needed for washing and dyeing fabrics, can contribute to substantial resource

savings. Additionally, reducing CO_2 emissions can be achieved through the transition to green energy, optimizing transportation chains, and reducing waste by introducing manufacturing techniques that use fewer materials. Some of the innovative approaches that are transforming the sector by reducing chemical use, conserving water, and lowering energy consumption are:

- Microbiological (Enzymatic) treatments – enzymes are used instead of toxic chemicals [7]
- Digital printing and dyeing – reduces water and chemical consumption compared to conventional methods [8].
- Biodegradable fabrics – such as Mylo™, made from fungal (mycelium) fibers [5].

These innovations not only represent technical advancements but also a response to global sustainability challenges [9]. Their implementation can significantly contribute to reducing the negative environmental impact of the textile industry, provided they are integrated into broader systemic changes – including legislative frameworks, consumer education, and responsible resource management.

4.1. Microbiological Treatments

Microbiological treatments employ natural enzymes as eco-friendly alternatives to harmful chemicals in textile processes. These enzymes act as biological catalysts to facilitate reactions at mild temperatures and neutral pH, decreasing resource use and environmental impact [7,10]. Key applications include:

- De-sizing: Amylases selectively break down starch used for sizing cotton, replacing corrosive acids and high-temperature processes, thus preserving fabric integrity and reducing effluent.
- Scouring and bleaching: Proteases, pectinases, cellulases and laccases clean impurities and prepare fibres for dyeing, significantly cutting water and chemical usage. Pectinases alone reduce water use by up to 67% and energy by 50% compared to conventional treatments.
- Biopolishing and finishing: Cellulases smooth fabric surfaces by removing microfibers (“fuzz”), improving appearance and feel without damaging fibers.
- Effluent treatment: Enzymes like catalase and peroxidase detoxify wastewater by neutralizing residual peroxide and breaking down unused dyes before disposal.

Enzymatic methods offer multiple benefits: reduced water and energy consumption, lower chemical pollution, milder processing conditions, and biodegradable residues [10]. However, higher enzyme costs and compatibility with industrial-scale processes remain challenges to widespread adoption.

4.2. Digital Dyeing

Digital dyeing, often delivered via inkjet or spray-based technologies, represents a revolution in sustainable textile coloration. Instead of bulk dye baths, inks are precisely jetted onto fabrics, drastically reducing water usage and dye waste [8,11].

- Water savings: Digital printing can cut water consumption by up to 90–97% compared to conventional methods.

- Reduced chemical use: Eliminates excess dye baths and rinse cycles, minimizing effluent volume and toxicity.
- Energy efficiency and precision: Offers high-resolution designs with low energy input and waste, ideal for on-demand and localized production.

Industry players like EFI Reggiani and Konica Minolta have released commercial systems boasting up to 90% water and 60% energy reductions, while Alchemie's spray-based digital dyeing entirely eliminates water in the dyeing phase [8,11]. Applications include sustainable silk scarves ("Water Silks") using Epson inkjet, which reduces water use by approximately 97% in printing.

4.3. Biodegradable fabrics

In the modern textile industry, increasing attention is given to the development of materials that combine functionality, aesthetics, and environmental sustainability. One of the most prominent innovative materials in this area is Mylo™, a biodegradable leather alternative made from mycelium which is a root-like structure of fungi [5].

Mylo™ is a product developed by the American biotechnology company Bolt Threads, in collaboration with major fashion brands such as Stella McCartney, Adidas, and Lululemon. The material closely resembles natural leather in both appearance and texture, but is produced without the use of animal-based or synthetic raw materials [13]. It is cultivated under laboratory conditions, where mycelium is grown on organic waste (e.g., sawdust) and transformed into a leather-like structure in just a few days, making it an exceptionally efficient and renewable resource [12].

The environmental benefits of Mylo™ are numerous [5,12]. Unlike conventional leather, its production does not involve livestock farming, thereby reducing greenhouse gas emissions, water consumption, and land use. Furthermore, compared to synthetic "vegan leather," which is often made from plastic, Mylo™ is biodegradable and does not generate long-lasting environmental waste.

Although Mylo™ is still in limited use due to high costs and low production volumes, its emergence represents a significant step toward a more circular and environmentally responsible textile industry. With continued technological development and expanded production capacities, this material is expected to become increasingly present in fashion collections that prioritize sustainability [13].

5. ETHICAL STANDARDS AND FAIR TRADE

Ethical standards and fair trade play a crucial role in ensuring that the textile industry respects human rights, working conditions, and environmental norms. Fair trade implies adhering to fair prices for products, which allows producers in developing regions to achieve stable economic conditions and improve social standards for their workers. In the context of the textile industry, fair trade also involves transparency in production, monitoring supply chains, and collaborating with small-scale farmers and fabric producers who follow social and environmental standards.

Additionally, the textile industry increasingly recognizes the importance of certifications such as Fair Trade, Global Organic Textile Standard (GOTS), and OEKO-TEX standards, which guarantee that products are made in accordance with strict environmental and social norms. These certifications enable consumers to make informed decisions about how and where they purchase products, thereby increasing demand for ethically produced fabrics. Respecting workers' rights, ensuring fair wages and safe working conditions, and adopting certifications such as GOTS, Fair Trade, OEKO-TEX, and Bluesign foster ethical and sustainable supply chains [14].

Key sustainability standards in textiles represent guidelines and certification systems that promote transparency, responsible resource management, respect for human rights, and the reduction of environmental impact throughout the textile production process [9]. These standards help companies align with ecological and ethical principles, and empower consumers to make informed decisions.

Below are listed the most important international sustainability standards and certifications in the textile sector.

Global Organic Textile Standard (GOTS)

Purpose: Certification of organic textiles and socially responsible production [15].

Main Features:

- Covers the entire supply chain: from raw material cultivation to the final product.
- Minimum of 70% materials must be organic, and 95% for the "organic" label.
- Prohibits the use of toxic chemicals, azo dyes, and heavy metals.
- Requires compliance with social criteria according to ILO standards

OEKO-TEX® Standard 100

Purpose: Testing textile products for harmful substances.

Main Features:

- Focused on consumer safety.
- Tests fabrics, dyes, buttons, zippers, etc.
- The “Confidence in Textiles” label indicates the product is safe for skin and health [14,16].

Bluesign®

Purpose: Reducing the harmful environmental impact of the textile industry.

Main Features:

- Strict chemical management throughout the production chain.
- Manufacturers must optimize the use of energy, water, and raw materials.
- Promotes process transparency and traceability across the value chain [14].

Fair Trade Textile Standard

Purpose: Ensuring fair labor conditions and fair pricing in the textile industry.

Main Features:

- Workers receive fair wages and work in safe conditions.
- Promotes workers' rights and prohibits child labor.
- Supports community development through a "Fair Trade Premium" [17].

Cradle to Cradle Certified®

Purpose: Designing products that are fully recyclable or compostable.
Main Features:

- Focus on circular economy: products must be “waste-free”.
- Assessment in five categories: material health, reuse, water stewardship, energy, and social fairness.
- Ideal for brands aiming for a closed-loop production system [18].

ISO Sustainability Standards in Textiles

- ISO 14001 – Environmental management systems.
- ISO 9001 – Quality management systems.
- ISO 20400 – Sustainable procurement
- ISO 26000 – Corporate social responsibility.

These standards are not only technical guidelines but also tools to strengthen consumer trust, protect the environment, and improve ethical practices in the textile industry. By implementing these ISO standards, companies:

- Reduce CO_2 emissions and water usage
- Eliminate hazardous chemicals
- Increase transparency across the supply chain
- Promote ethical labor and social responsibility

6. CONCLUSION

Sustainability in the textile industry is no longer an option, but a necessity. By using eco-friendly materials, applying circular economy principles, and focusing on innovation and global standards, the industry can shift toward more responsible practices. Many real-world examples show that being sustainable can actually provide a competitive edge. However, achieving this shift requires collaboration among the industry, regulators, and consumers. This paper can serve as an example for companies in the textile sector on how to improve and enhance existing operations towards a responsible and sustainable business model. Furthermore, it highlights the importance of continuous innovation and monitoring to ensure long-term success in adopting sustainable practices across the sector.

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SULFATES FROM TEXTILE EFFLUENTS AS AN AGRICULTURAL RISK: A CASE STUDY ON BASIL

Original scientific paper
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ABSTRACT: *Sulfate contamination of textile wastewater (TWW) is a growing concern in water reuse strategies for agriculture. In this study, the effects of untreated TWW with different sulfate concentrations on basil (Ocimum basilicum) were investigated. Two wastewater samples were used: one with high sulfate content (240.8 mg/L) and one with low (21.58 mg/L). No visible phytotoxic effects were observed, but basil irrigated with the high sulfate sample showed reduced shoot height (13.2 cm) compared to 17.8 cm in the low sulfate treatment. The sulfur concentration in the soil was significantly higher in the low sulfate irrigation (11357 mg/kg) than in the high sulfate irrigation (4600 mg/kg). This unexpected result could be due to differences in wastewater composition, sulfur speciation, microbial activity, or plant uptake dynamics. While basil proved resilient to elevated sulfate levels, the study shows how untreated TWW can affect both plant growth and soil chemistry in complex and nonlinear ways. These results underscope the need for detailed characterization of wastewater prior to reuse in agricultural.*

Keywords: *Textile wastewater, Sulfates, Basil, Soil accumulation, Irrigation.*

SULFATI IZ TEKSTILNIH OTPADNIH VODA KAO RIZIK ZA POLJOPRIVREDU: STUDIJA SLUČAJA O BOSILJKU

APSTRAKT: *Onečišćenje sulfatima iz tekstilnih otpadnih voda (TOV) predstavlja sve veći problem u strategijama oporabu (ponovne primjene) vode u poljoprivredi. Ovo istraživanje procijenjuje utjecaj neobrađenih tekstilnih otpadnih voda s različitim koncentracijama sulfata na bosiljak (Ocimum basilicum). Primijenjena su dva uzorka otpadne vode: jedan s visokim sadržajem sulfata (240,8 mg/L) i jedan s niskim (21,58 mg/L). Vidljivi fitotoksični učinci nisu uočeni, ali bosiljak navodnjavan uzorkom s visokim sadržajem sulfata pokazao je smanjenu visinu izboja (13,2 cm) u usporedbi s 17,8 cm kod tretmana s niskim sadržajem sulfata. Koncentracije sumpora u tlu bile su značajno više*

kod navodnjavanja vodom s niskim sadržajem sulfata (11357 mg/kg) nego kod navodnjavanja vodom s visokim sadržajem sulfata (4600 mg/kg). Ovaj neočekivani rezultat može se pripisati razlikama u sastavu otpadne vode, specijaciji sumpora, mikrobnoj aktivnosti ili dinamici usvajanja sumpora od strane biljaka. Iako je bosiljak pokazao otpornost na povišene razine sulfata, ovo istraživanje naglašava kako neobrađene tekstilne otpadne vode mogu utjecati na rast biljaka i kemizam tla na složen i nelinearan način. Ovi rezultati podupiru potrebu za detaljnom karakterizacijom otpadnih voda prije njihove oporabe u poljoprivredi.

Ključne reči: *Tekstilna otpadna voda, sulfati, bosiljak, akumulacija u tlu, navodnjavanje.*

1. INTRODUCTION

The increasing scarcity of freshwater resources worldwide has led to wastewater increasingly being used for agricultural irrigation [1]. Among the various industrial sectors, the textile industry is one of the largest consumers and polluters of water and generates significant amount of textile wastewater (TWW). Textile wastewater is characterized by a complex composition containing high concentrations of dyes, salts, heavy metals, and various organic and inorganic contaminants [2]. A particularly worrying component of TWW is sulfate, an anion that is essential for plant growth in trace amounts, but can be harmful in increased quantities.

Sulfates are used extensively in the textile industry, especially in reactive dyeing processes. Sulfates, especially in the form of Glauber's salt ($Na_2SO_4 \times 10H_2O$), act as important electrolytes that facilitate the exhaustion of dyes from solution onto the fiber surface by reducing the negative charge repulsion between the dye molecules and the cellulose fibers. This role is critical for uniform dye fixation, color strength, and production efficiency [3]. Without the addition of sulfates, reactive dyes would largely remain in solution and would not bind sufficiently to the textile material. Due to their extensive use, significant amounts of sulfates are released into textile effluents, leading to increased sulfate concentrations in wastewater streams [4]. When such untreated or poorly treated wastewater is used for agricultural irrigation, the high sulfate load can significantly affect soil properties and plant health, raising concerns about long-term soil sustainability and crop productivity.

Sulfates in irrigation water can accumulate in the soil over time, altering soil chemistry and potentially affecting plant health. Excessive sulfate concentrations can lead to soil salinization, impair soil structure, and interfere with the uptake of other important nutrients such as calcium and magnesium [5]. In plants, elevated sulfate levels can cause osmotic stress, inhibit growth, and reduce crop yield and quality [6]. Given the increasing interest in the use of untreated or partially treated industrial wastewater for irrigation, it is important to understand the specific risks associated with sulfate accumulation.

Despite the known risks, there is little research that specifically addresses the effects of sulfate-rich TWW on agricultural soils and crops. Most studies focus on organic pollutants or heavy metals, often overlooking the cumulative and subtle effects of high sulfate levels [7]. However, since sulfate is highly mobile in soil-water systems and can persist over long

periods of time, its role in soil degradation and plant physiological responses deserves greater attention.

Basil (*Ocimum basilicum*), a widely cultivated herb valued for its culinary, medicinal, and aromatic properties, provides an excellent model for studying the effects of sulfate contamination. Basil is relatively sensitive to soil salinity and nutrient imbalances [8], making it a good indicator species for assessing impacts on wastewater quality. Since basil is often consumed fresh, soil and water quality concerns translate directly into food safety issues, further emphasizing the importance of careful water management during cultivation. Previous research has shown that different crops have different tolerances to sulfate and the associated salt stress. For example, studies by Maas and Grattan (1999) established thresholds for the salt tolerance of numerous crops, but specific guidelines for sulfate concentrations remain poorly defined [9]. This knowledge gap emphasizes the need for crop-specific studies on the impact of sulfate-enriched effluents. In addition, sulfate dynamics in soil systems are influenced by numerous factors, including soil type, microbial activity, water management practices, and the chemical composition of the wastewater [10]. Sulfate can interact with soil minerals and organic matter, undergo microbial transformations such as reduction to sulfide under anaerobic conditions, and participate in complex nutrient cycling processes. These interactions make the prediction of the consequence of sulfate contamination by textile wastewater in agricultural even more complex.

In view of these considerations, this study aims to evaluate the effects of textile wastewater with different sulfate concentrations on the growth performance of basil and sulfur accumulation in the soil. By analyzing the results of irrigation with high-sulfate and low-sulfate TWW samples, we aim to provide insight into the risks and challenges associated with the agricultural reuse of textile wastewater. In addition, this research highlights the importance of comprehensive wastewater characterization, not only with respect to traditional pollutants, but also secondary pollutants such as sulfate, which can have significant ecological and agronomic consequences. Understanding the impact of sulfate contaminants on crops such as basil is critical to developing sustainable wastewater reuse strategies. It helps to establish safe guidelines for irrigation practices, soil management, and crop selection to ultimately support efforts to reduce the environmental footprint of industrial activities while safeguarding agricultural productivity and food quality.

2. MATERIALS AND METHODS

Untreated TWW samples were collected from a textile factory in Omiš, Croatia, in particular from processes dominated by dyeing activities known to contribute significantly to sulfate contamination. Two different wastewater samples were selected for the study: one with a high sulfate concentration and one with a lower sulfate concentration. The sulfate concentration in the wastewater samples was determined before irrigation started. Standard methods for the quantification of sulfate in water were used (HRN EN ISO 10304-1:2009).

The basil plants were cultivated in pots filled with a commercially available vegetable substrate (Potgrond H). Each pot was filled with about 340 cm³ of substrate. Four basil seeds were planted in each pot at a depth of about 1 cm. The plants were irrigated daily over a period of 21 days with 75 mL of one of the two collected TWW samples. Controlled environmental conditions were maintained: a temperature of 24.2 ± 0.8 °C, a relative humidity of 47.2 ± 2.3%, and 16 hours of light per day from LED lamps.
At the end of the irrigation period, soil samples were taken from each pot and analyzed for total sulfur content. The soil samples were dried and prepared according to the standard method HRN ISO 11464:2004. The sulfur content was determined using portable X-ray fluorescence spectroscopy. The shoot height of the basil plants was measured after 21 days of irrigation. Shoot height was measured recorded from the base of the stem at soil level to the apex of the main shoot using a digital ruler. Measurements were taken for all plants to evaluate the effects of different sulfate concentrations on plant growth.

3. RESULTS AND DISCUSSION

The sulfate concentrations measured in the two TWW samples showed considerablr variability. The high sulfate sample contained 240.8 mg/L sulfate, while the low sulfate sample contained 21.58 mg/L. These differences reflect the variability to be expected in untreated TWW, which is influenced by the type of the processes and the amount of chemicals used in production. The measured sulfate concentrations in TWW samples and the corresponding sulfur concentrations in the soil after irrigation are shown in Table 1. Such variability emphasizes the need for regular monitoring of industrial effluents intended for agricultural reuse, as inconsistent chemical compositions can lead to unpredictable effects on soils and plant systems.
After irrigation the basil plants with the two TWW samples, differences were also found in the sulfur concentrations in the soil. Soils irrigated with the low sulfate TWW sample showed significantly higher sulfur accumulation (11357 mg/kg) than soils irrigated with the high sulfate sample (4600 mg/kg). This result was unexpected as it is generally assumed that a higher sulfate input would lead to a higher sulfur content in the soil. Several factors could explain this discrepancy, including differences in sulfur speciation, microbial activities affecting sulfur cycling, or different plant uptake rates that could have reduced the available sulfur in the soil under high sulfate conditions [11]. In addition, soil characteristics such as texture, organic matter content, and pH may have influenced sulfur retention and mobility, highlighting the complex interactions within the soil matrix when irrigated with TWW.
The height of basil plants was used as an indicator of the effects of sulfate concentration on plant growth. Plants irrigated with high sulfate TWW had an average shoot height of 13.2 cm, while plants irrigated with low sulfate TWW reached an average height of 17.8 cm. Although no visible signs of phytotoxicity were observed, the reduction in shoot height suggests that elevated sulfate concentrations may impose a form of sublethal stress on basil plants, possibly through osmotic effects that inhibit water uptake and limit cell expansion [12].

Prolonged exposure to high levels of sulfate could potentially lead to cumulative negative effects on plant biomass and yield, especially under conditions of high evapotranspiration that enhance salt accumulation. Therefore, even moderate differences in sulfate concentration in irrigation water can have significant effect on plant performance over time.

Table 1: The measured sulfate concentrations in TWW samples and the corresponding sulfur concentrations in the soil after irrigation.

Sample	Sulfate concentration in TWW (mg/L)	Soil sulfur concentration (mg/kg)
High sulfate TWW	240.80	4600
Low sulfate TWW	21.58	11357

4. CONCLUSIONS

The results of this study show that untreated TWW with varying sulfate concentrations can affect both soil chemistry and basil growth in unexpected ways. Despite higher sulfate levels in one sample, sulfur accumulation in the soil was greater when treated with the lower sulfate concentration, highlighting the complexity of soil–plant interactions. Although basil plants were resilient to elevated sulfate concentrations, the reduced shoot height under high sulfate irrigation indicates possible stress effects. These results emphasize the need for careful evaluation and monitoring of industrial wastewater prior to their application in agriculture to ensure sustainable soil management and crop health.
Textile wastewater is an increasingly attractive alternative source of water for agricultural irrigation due to it high volume and nutrient content, especially in regions where water is scarce. However, its complex composition, including high concentrations of salts, dyes, and auxiliary chemicals such as sulfates, requires thorough testing before reuse. Improper use of untreated TWW can lead to soil degradation, lower crop productivity, and potential environmental pollution. Therefore, future strategies should focus on developing appropriate treatment technologies, water quality standards, and management practices that enable safe and beneficial reuse of TWW in agriculture. Integrating wastewater reuse with sustainable agricultural practices could significantly contribute to alleviating freshwater scarcity, but only if the focus is on continuous monitoring, risk assessment, and soil-plant system management.

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REDUCING TEXTILE WASTE THROUGH DIGITAL TECHNOLOGIES: CASE STUDY OF CLO 3D AND AUDACES IN FASHION DESIGN

Professional paper
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ABSTRACT: *The work deals with the problem of excessive generation of textile waste in the fashion industry, with a special focus on the stages of design and production of clothing. Modern methods and digital technologies that enable waste minimization are analyzed, including zero-waste design, 3D simulations, digital prototyping and artificial intelligence. Special attention is paid to CLO 3D and Audaces software solutions, which enable more precise tailoring, optimization of material consumption and more efficient production of clothing. The implementation of these technologies contributes to sustainability, reducing the negative impact on the environment and moving towards a circular model of the fashion industry.*

Keywords: *textile waste, digital fashion, zero-waste design, CAD systems, sustainable production.*

SMANJENJE TEKSTILNOG OTPADA UZ POMOĆ DIGITALNIH TEHNOLOGIJA: STUDIJA SLUČAJA CLO 3D AND AUDACES SOFTVER

APSTRAKT: *Ovaj rad se bavi problemom prekomernog nastanka tekstilnog otpada u modnoj industriji, sa posebnim fokusom na faze dizajna i proizvodnje odeće. Analiziraju se savremene metode i digitalne tehnologije koje omogućavaju minimizaciju otpada, uključujući zero-waste dizajn, 3D simulacije, digitalno prototipiranje i veštačku inteligenciju. Posebna pažnja posvećena je softverskim rešenjima CLO 3D i Audaces, koja omogućavaju preciznije krojenje, optimizaciju potrošnje materijala i efikasniju proizvodnju. Implementacija ovih tehnologija doprinosi održivosti, smanjenju negativnog uticaja na životnu sredinu i prelasku ka cirkularnom modelu modne industrije.*

Ključne reči: *tekstilni otpad, digitalna moda, zero-waste dizajn, CAD sistemi, CLO 3D, održiva proizvodnja*

1. INTRODUCTION

The fashion industry is one of the most dynamic, but also the most environmentally problematic sectors of the modern economy. Fast fashion has led to a drastic increase in the production and consumption of clothing, resulting in huge amounts of textile waste. Currently, more than half of discarded clothing ends up in landfills or incinerators, while less than 1% of textile materials are recycled back into new clothing. This trend indicates an urgent need to change production and consumption models in the fashion industry to reduce the negative impact on the environment [1,2].
Waste prevention through clothing design is a key approach to reducing the negative impact, where modern digital tools such as 3D modeling, virtual prototyping and artificial intelligence play a significant role. These technologies enable more precise design, optimization of production and tailoring of clothing, thereby reducing the amount of textile waste [1,2].

2. METHODS FOR REDUCING WASTE IN THE GARMENT DESIGN PHASE

Waste in the fashion industry can be classified into several categories:

- **Garment design waste** - waste generated during designing, tailoring and production, including fabric scraps and incorrect patterns.
- **Production waste** – production waste and defective items created during mass production.
- **Post-consumer waste** - clothing that is discarded after use, including unsold stock [3].

The traditional garment design and manufacturing process tolerates two types of material loss:

- ***material losses of subjective reasons*** - caused by the flexibile structure of textile materials and the use of imperfect methods of creating markers, laying and cutting parts of clothing items.
- ***material losses of objective reasons*** - they arise due to complicated and fixed shapes of components, the need for the same and precise coordination of patterns on ready garments, specific properties of textile materials (different properties in the direction of warp and weft, edges, patterns, pile of materials, etc.) [4].

In order to reduce the loss of material due to the inefficient shapes of garment components, the fashion industry should focus on making styles with simplified forms but attractive designs using different colors, prints and surface decorations. Textile materials have to become a "precious resource" again, not only because of their increasing prices, but also because of the serious environmental problems caused by textile waste.
Reducing waste in the fashion industry is becoming a key aspect of sustainable production. Already at the stage of clothing design, by applying various techniques and technologies, it is possible to minimize waste and improve the efficiency of the production process. The methods used to reduce waste are [5]:

2.1. Optimization of material laying and cutting process

CAD (Computer-Aided Design) systems allow designers to plan precisely the arrangement of cut components on the fabric and with it to reduce unnecessary material waste. This process is known as "nesting", where the computer analyzes the optimal distribution of components on the fabric, taking into account its characteristics and specifics.

The use of automatic nesting reduces human error and allows for greater precision, resulting in less waste.

2.2. Zero-waste design

This method involves designing clothing in a way that completely eliminates waste, by cutting all parts of the garments from one piece of fabric, with no scraps. Zero-waste designers often use mathematical algorithms and creative techniques to connect all the cut parts and combine them into a single structure that leaves no waste. This approach is especially effective for creating simple, minimalist pieces like dresses, skirts, and shirts.

2.3. The use of recycled and ecological materials

Recycled materials, such as recycled plastic (PET) fabrics, old clothes or even agricultural waste can be used in the design phase. This reduces the need for new resources, thereby reducing the amount of waste in the production process.

Designers can use sustainable materials such as organic cotton, bamboo, or recycled synthetic fabrics that are more environmentally friendly and often easier to recycle.

2.4. Modular and transformable design

Modularni dizajn podrazumeva kreiranje odeće koja se može prilagoditi i transformisati na različite načine, čime se smanjuje potreba za novim proizvodima i višestrukim kupovinama. Na primer, jakna koja može postati prsluk, ili haljina koja se može pretvoriti u suknju.Multifunkcionalni komadi omogućavaju da jedan proizvod ima više namena, čime se smanjuje broj odeće koja se mora proizvoditi i kupovati, a time i količina otpada.

Modular design means creating clothes that can be adapted and transformed in different ways, thus reducing the need for new products and multiple purchases. For example, a jacket that can become a vest, or a dress that can be turned into a skirt. Transformable garments allow one product to have more than one purpose, thus reducing amounts of clothing that must be produced and purchased.

2.5. Upcycling and use of left over materials

Upcycling je proces u kojem se stari komadi odeće ili tkanine pretvaraju u nove, vrednije proizvode. Dizajneri mogu koristiti ostatke tkanina iz prethodnih kolekcija ili odbačene komade i preoblikovati ih u nove komade odeće, čime se smanjuje potreba za novim sirovinama.Ovaj pristup ne samo da smanjuje otpad, već i omogućava kreativan rad i jedinstvene proizvode.

Upcycling is the process of turning old pieces of clothing or fabric into new, more valuable products. Designers can use leftover fabrics from previous collections or discarded pieces

and transform them into new clothing, thus reducing the need for new raw materials. This approach not only reduces waste, but also enables creative work and unique products.

2.6. Using 3D simulations and digital prototyping

3D simulacije i digitalni prototipi omogućavaju dizajnerima da testiraju kako će proizvod izgledati na telu pre nego što započne fizička proizvodnja. To znači da se smanjuje potreba za fizičkim uzorcima i testiranjima, čime se štedi materijal.
Virtuelno isprobavanje uz pomoć specijalizovanih softvera omogućava da se dizajnira odeća sa potpunom preciznošću bez potrebe za višestrukim stvaranjem prototipova, čime se smanjuje količina otpada.
3D simulations and creation of digital prototypes allow designers to test how a ready garments will look on the body before physical production begins. This means that the need for physical samples and testing is reduced, saving material.
Virtual fitting with the help of specialized software makes it possible to design clothes with complete precision without the need for multiple prototypes, thus reducing the amount of waste.

2.7. Data-driven demand forecasting

Analyzing data on consumer habits, trends and preferences can help designers more accurately predict which clothes will be in demand, thereby reducing surplus production.
By introducing machine learning algorithms, it is possible to predict exactly how many pieces of certain styles should be produced, which allows greater precision in production planning.

3. OVERVIEW OF DIGITAL TECHNOLOGIES FOR CLOTHING DESIGNING AND PRODUCTION

The development of digital technologies has transformed the clothing design process, enabling designers and the industry to reduce waste, optimize material consumption and speed up the production cycle. Digitization in the fashion industry includes a wide range of tools, from computer-aided design (CAD) to artificial intelligence (AI) and virtual prototyping [6].

4. CASE STUDY: CLO 3D I AUDACES

4.1. CLO 3D

The CLO 3D program was developed by a team of experts at the Korean company "CLO Virtual Fashion Inc." and was presented for the first time in 2009. It was created in response to the need for a more efficient and precise way of designing clothes. It enables the simulation of garments in a virtual space before the production is started. Over the years, CLO 3D has experienced dynamic development, with frequent upgrades bringing new advanced cut and fabric simulation tools, improved user interface, and better integration with other software solutions [7].

One of the reasons for the popularity and application of this computer program is its effort to maximize the use of material (cut optimization), which directly contributes to the preservation of the environment through the reduction of textile waste (inter-cut loss), which is extremely important for the textile industry [7].
CLO 3D enables the creation of digital clothing prototypes that can be viewed from all angles, i.e. in a 3D virtual space, while simulating the fabric's behavior in real conditions [7].
Key functions of the CLO 3D program are:

- Simulation of a specific design and its adaptation as needed (see Fig.1),
- A significant reduction of the time required for product development,
- Accurate simulation of different fabrics, taking into account texture, weight and stretch,
- 3D visualization of clothing for improved product presentation,
- Creating personalized avatars and testing clothes on different body types [7].

4.1.1. *Advantages of CLO 3D program*

- Reduction of production costs – saves time and resources.
- Faster decision-making – enables quick changes and design reviews.
- More accurate fabric simulation – reduces the risk of errors in the later stages of production.
- Reduction of textile waste - reduction of the number of physical prototypes.
- Better fit and sizing – ability to test different fits on avatars.

Figure 1: Creation of 3D virtual style by CLO 3D[7]

4.1.2. *Disadvantages of CLO 3D program*

- Without clearly defined guidelines, simulation results can vary even when using the same basic data (avatars, cut parts, materials).
- Although developing simulation guidelines is time-consuming, it is critical to achieving reliable and consistent results.

- Also, guidelines should be regularly updated due to frequent upgrades of 3D simulation systems, which develop new functions and tools[7].

4.1.3. CLO 3D *Software's contribution to sustainability*

Računarska izrada prototipova modela i simulacija odeće pre početka proizvodnje izuzetno su važni za smanjenje tekstilnog otpada i održivu proizvodnju. Ovo važi kako za klasične metode konstruisanja odeće, tako i za zero-waste pristup [7].

Na slici 3. prikazana je pored smanjenja otpada, 3D simulacija koja omogućava preciznije prilagođavanje modela različitim tipovima tela, čime se poboljšava pristajanje i estetski kvalitet odevnog predmeta.

Computer-aided prototyping of models and simulation of garments before production is started are extremely important to reducing textile waste and support sustainable production. This is important for both to classical methods of constructing clothes and to the zero-waste approach [7].

Figure 2 shows how in addition to waste reduction, a 3D simulation that enables more precise adaptation of the style to different body types, thereby improving the fit and aesthetic quality of the garment.

Figure 2: Adaptation of the style to different body types [7]

Limitations in fitting or lack of aesthetic criteria in the initial design idea can be corrected in pre -production phase, thus ensuring better acceptance of the product by consumers.

4.2. Audaces

Audaces is an integrated software system developed for the digital construction, modeling and optimization of clothing production. This software enables faster and more precise designing of patterns, automatic gradation of patterns and optimization of material consumption. Audaces can be used at small design studios and also at large capacity production sites. It enables cost reduction, increased efficiency and more sustainable production.

Audaces is particularly popular in the industrial manufacturing of clothing, as it combines 2D and 3D tools that help optimize the entire process, from designing to tailoring and manufacturing of the final products [8].

4.2.1 ***Main chracteristics and modules of Audaces Softwere***

Audaces offers several software modules, which together enable a complete digital clothing design process, (see Fig.3) [8].

4.2.2. ***Audaces 360 - Integrated ecosystem for digital design:***

- A complete solution for all phases of product development,
- Digital model archive for faster search and collection management,
- Connectivity with CAD and 3D tools for better design optimization [8].

Figure 3 : Audaces Softwere

4.2.3. ***Audaces Idea - Software for Fashion Design and Technical Sketching:***

- Enables the creation of technical drawings and fashion illustrations,
- Generates automatic size tables and technical specifications,
- Connects to tailoring systems for easier data transfer [8].

4.2.4. ***Audaces 360 - Integrated ecosystem for digital design***

- A complete solution for all phases of product development,
- Digital model archive for faster search and collection management,
- Connectivity with CAD and 3D tools for better design optimization [8].

4.2.5. ***Audaces Idea - Software for Fashion Design and Technical Sketching***

- Enables the creation of technical drawings and fashion illustrations,
- Generates automatic size tables and technical specifications,
- Connects to tailoring systems for easier data transfer [8].

5.2.6. ***Audaces Pattern - Digital Construction of Patterns (CAD Software)***

- Digital construction of cuts with precise lines and shapes,

- Automatic gradation to create multiple sizes from one basic model,
- The possibility of optimizing cutting parts in order to reduce material waste [8].

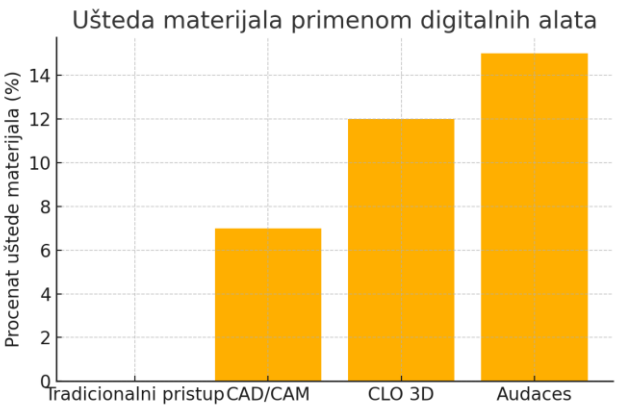

Figure 4: Material savings using CLO 3 and Audaces Softwere

5. CONCLUSION

The analysis of CLO 3D and Audaces software solutions clearly shows how modern digital technologies significantly contribute to the improvement of the process of designing and manufacturing clothes. CLO 3D stands out as a powerful tool for 3D garment simulation, enabling realistic rendering of models, adapting to different body types and significantly reducing the need for physical prototypes. This software not only speeds up the design process, but directly contributes to sustainability through cut optimization and reduction of textile waste.

On the other hand, Audaces represents a comprehensive system that integrates all stages of the development of a clothing product - from the idea and sketch, through the construction of patterns, to the optimization of manufacturing. Its modular structure ensures its flexible use depending on the user's needs, while the connection of 2D and 3D functionality ensure greater precision, efficiency and resource savings.

What both systems have in common is the contribution to the digitalization of the fashion industry and the transition to sustainable practices. The use of CLO 3D and Audaces software not only reduces production costs and time, but also increases the quality of final products, enabling better adaptation to the market and end users. Their integration into fashion and textile processes represents a key step towards the modernization of the industry and a more responsible approach to clothing production.

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[8] https://audaces.com/en

SIGNIFICANCE AND ROLE OF RECYCLING TEXTILE PRODUCTS IN THE CONCEPT OF CIRCULAR ECONOMY

Review paper
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ABSTRACT: *The recycling of textile products is a topic that is very current in modern society, primarily because of the extremely large amounts of this type of waste that are disposed of in landfills. Due to the changes that are taking place in it and the shorter period of use of clothing, the textile industry has become one of the activities that have a high share in the total amount of generated waste on a global level. This paper investigates the importance and role of recycling textile products in the concept of circular economy, which aims to ensure the sustainable development of all segments of modern society. The subject of the research carried out in the paper should indicate the need for a much greater application of recycling in the textile industry and the positive effects it can lead to. The goal of the research is to point out the importance of recycling textile products and the role it plays within the framework of the circular economy concept. The results of this research can serve as a basis for further discussions regarding the importance and role of recycling textile products in the circular economy.*

Keywords: *Recycling, textile products, textile industry, circular economy, waste.*

ZNAČAJ I ULOGA RECIKLAŽE TEKSTILNIH PROIZVODA U KONCEPTU CIRKULARNE EKONOMIJE

APSTRAKT: *Reciklaža tekstilnih proizvoda predstavlja temu koja je veoma aktuelna u savrmenom društvu, pre svega zbog izuzetno velikih količina ove vrste otpada koje se odlažu na deponije. Zbog promena koje se u njoj dešavaju i sve kraćeg perioda korišćenja odeće, tekstilna industrija je postala jedna od delatnosti koje imaju visoko učešće u ukupnim količinama generisanog otpada na globalnom nivou. Ovaj rad istražuje značaj i ulogu reciklaže tekstilnih proizvoda u konceptu cirkularne ekonomije, koja ima za cilj da obezbedi održivi razvoj svih segmenata savremenog društva. Predmet istraživanja koje je obavljeno u radu treba da ukaže na potrebu za mnogo većom primenom reciklaže u tekstilnoj industriji i pozitivne efekte do kojih ona može dovesti. Cilj istraživanja je da*

ukaže na važnost reciklaže tekstilnih proizvoda i ulogu koju ona ima u okvirima koncepta cirkularne ekonomije. Rezultati ovog istraživanja mogu poslužiti kao osnova za dalje diskusije u vezi sa značajem i ulogom reciklaže tekstilnih proizvoda u cirkularnoj ekonomiji.

Ključne reči: *Reciklaža, tekstilni proizvodi, tekstilna industrija, cirkularna ekonomija, otpad.*

1. INTRODUCTION

The recycling of textile products is of great importance in the circular economy, which is reflected above all in the minimisation of waste after the end of use of these products, the reduction of the use of raw materials that come from nature and the extension of the product's lifespan. The concept of the circular economy is based on maximizing the use of textile materials through their reuse, repair, or recycling. The goal of all these activities is the maximum possible reduction of the negative impacts of the textile industry on the environment, which are currently very large. The importance of applying the concept of circular economy is additionally increased by the fact that the textile industry is classified as one of the activities that have the greatest negative impact on the environment.
The quantities of textile waste that are generated represent a significant threat to the environment. The degree of recycling of textile products that are no longer used is very low, which is why it is essential to increase their use in the textile industry. The negative effects that arise as a result of textile waste are further increased due to its ever-increasing amount, which is a consequence of the application of the concept of fast fashion, which implies a short lifespan of clothes and the cessation of use of products that are still functionally and aesthetically completely correct. Given this fact, it is necessary to emphasise the application of the circular economy concept in order to increase the proportion of textile products that are recycled or reused at the end of their life cycle.

2. CIRCULAR ECONOMY

The circular economy mainly focuses on lengthening product lifespans to lessen environmental damage [1]. The practical application of this concept is based on sharing, borrowing, reusing, repairing, and recycling existing materials and products as much as possible. After the end of the life of the product, the materials from which it is made are recycled, and their use continues, most often for the production of new products. This process of recycling products and reusing materials continues continuously, in order to ensure the minimization of the amount of waste that is disposed of [2].
The concept of the circular economy is based on approaches that are completely different from the traditional linear model, in which raw materials are used for the production of various products, which are used and at the end of their life cycle are thrown away, i.e., disposed of in landfills. The traditional linear model is based on the use of large quantities

of cheap and readily available materials and energy sources. The textile industry is one of the economic sectors that generates extremely large amounts of waste, which is why the application of the circular economy concept can have a significant positive economic and environmental impact. The UN Sustainable Development Agenda 2030 defines the basic goals of the development of modern society. Within this agenda, the transition to a circular economy is defined as one of the most important goals in the area of environmental protection and climate change prevention [3]. The circular economy is an instrument for achieving the goals of sustainable development. It includes various long-term investments in raw materials, energy efficiency, pollution reduction, use of renewable energy sources, and implementation of sustainable production and trade models [4]. The functioning of the circular economy concept is shown in Figure 1.

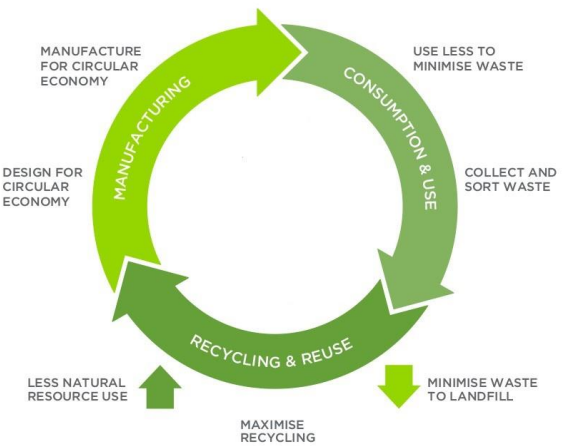

Figure 1: Conceptual model of the circular economy [5]

The circular economy is a modern concept that is much narrower in scope than sustainable development. The most significant similarities between the circular economy and sustainable development can be singled out as commitment to long-term goals that are passed on to future generations, the application of global models, multidisciplinary research areas, innovative business models, and the use of modern digital technologies [4]. The main difference between these two concepts is that the circular economy is a newer and narrower concept, focussing on economic and environmental benefits, as opposed to sustainable development, which has a much broader scope and encompasses all areas of society's functioning.

3. IMPACTS OF THE TEXTILE INDUSTRY ON THE ENVIRONMENT

The textile industry, in modern society, has extremely large negative effects on the environment. These negative effects are constantly increasing, as a consequence of the development of fast fashion, which is based on the sale of products of lower quality and

price. Fast fashion products are meant to be used for only one season, after which they are discarded and become waste, despite the fact that most of them are still fully functional and usable. The emphasis on fast fashion products allows manufacturers to significantly increase the amount of products sold and the profits made, while at the same time having a major negative impact on the environment.

The negative impact of the textile industry is best illustrated by the data that more than 100 billion garments are produced worldwide every year, emitting more than 1.2 billion tonnes of carbon dioxide into the atmosphere and dumping more than 500 thousand tonnes of microplastic fibres into the oceans [6]. In 2024, around 92 million tonnes of textile waste were generated worldwide at various stages of its life cycle, with more than half of this waste consisting of products that have reached the end of their life cycle and can still be used [7].

The negative impacts of the textile industry and the potential of applying the concept of circular economy in it can best be seen based on the data that only between 15 and 20% of fashion products whose life cycle is over are collected for reuse and recycling. More than 80% of clothes that are no longer used are disposed of in landfills or burned, which results in greater atmospheric pollution, as well as unnecessary losses of energy and raw materials [8]. The negative impacts that arise in the textile industry make it necessary to apply the concept of the circular economy and focus on recycling clothing after end of use.

During the last three decades, companies operating in the textile industry have been implementing various activities aimed at increasing business sustainability and reducing negative environmental and economic effects. The goal of these activities is to create an image of companies that care about the environment in the public, considering that the sustainability of fashion products and the way they are produced are factors that increasingly influence customers when making purchasing decisions.

The main actions that manufacturers are taking to fulfil the requirements for environmentally friendly products and sustainable business are the production of environmentally friendly products, the use of transparent supply chains, the reduction of negative impacts on the natural environment, reuse, recycling and the manufacture of new products made from products that have reached the end of their useful life [9].

4. APPLICATION OF RECYCLING AND CIRCULAR ECONOMY IN THE TEXTILE INDUSTRY

The application of the circular economy in the textile industry aims to maximise the lifespan of the textile products [10]. Maximizing product life can be achieved by using product design that eliminates waste, product reuse, repair, resource sharing, and recycling. The degree of need for the application of the circular economy in the textile industry can best be seen based on the fact that more than 50% of waste in it is generated in the phase after the end of product use [11]. An effective and widely implemented clothing recycling policy can significantly reduce the negative effects on the environment that arise as a result of this type of waste.

In addition to reducing negative impacts on the environment, the application of recycling textile products, as part of the circular economy concept, can lead to numerous additional positive effects. The recycling of textile products can lead to significant employment opportunities and the development of companies engaged in these activities, thereby generating significant benefits for local communities. One of the arguments against recycling in the textile industry is that it will lead to the loss of jobs in its parts that deal with fiber production. This reduction cannot be seen as a negative consequence due to the fact that it will be offset by the creation of new jobs in recycling and the collection of textile waste.

The insufficient level of application of the circular economy in the textile industry is largely a consequence of the absence of strategic plans to increase business sustainability at the global and national levels. These plans, and the legal regulations that would ensure their effective implementation, would place before the manufacturers of textile products the obligation to put more emphasis on the sustainability of their business and the negative effects on the environment that it leads to. A major problem in the application of recycling in the textile industry is the socio-economic and behavioural aspects, which have a highly negative impact on its practical implementation [8].

The circular economy provides a model that enables the transformation of the way the textile industry operates and the transition from the application of a linear model to a circular model, which ensures the sustainable operation of this economic branch in the future [12]. The implementation of the circular economy requires governments, businesses, and customers to abandon the classic extractive model of industrial production, which is based on the concept of "take, make, throw away". The circular economy aims to redefine business models and growth by focussing on achieving positive effects for the whole community, not just for its individual members.

The main goal of the circular economy is to ensure the preservation of the value of materials at the maximum possible levels during their movement through value chains. The circular economy should enable the value of materials and raw materials used in the textile industry to be preserved as long as possible. Recycling represents an approach that enables the achievement of circular economy goals through the reuse of materials from which textile products are made. The importance of recycling is demonstrated by the fact that it reduces the consumption of natural resources and the negative impact on the environment resulting from economic activities, while at the same time improving well-being and quality of life [12].

The activities carried out in the circular value chain of the textile industry are shown in Figure 2. By analyzing the activities shown in the figure, it can be concluded that a large part of them is, in a direct or indirect way, connected with recycling. The importance of recycling in the textile industry is further increased due to changes in the ways of consumption of fashion products, which result in an increase in their sales, a shortening of their life span, and the rejection of clothes that can be used functionally and aesthetically [13].

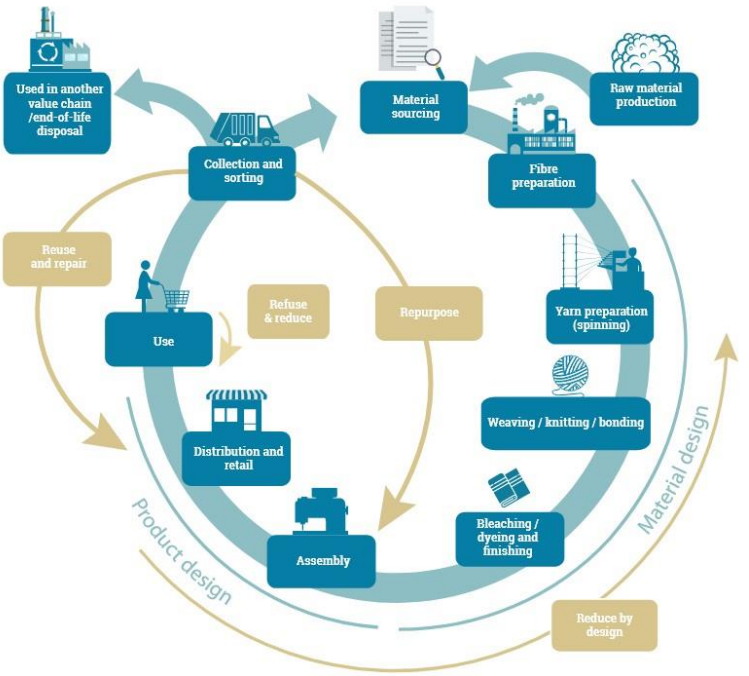

Figure 2: Activities carried out in the circular value chain of the textile industry [12]

Within the framework of the United Nations Sustainable Development Agenda 2030, the goal is defined that by the end of 2025, 45% of the polyester found in textile products must be recycled. For the year 2030, this document defines the goal that even 90% of these products must go through the recycling process [12]. Based on the actual status of the recycling of textile products whose use has been discontinued, it can be concluded that the stated targets are too optimistic and cannot be achieved

5. POSSIBILITIES FOR IMPROVING THE APPLICATION OF RECYCLING IN THE TEXTILE INDUSTRY

Despite the increasing attention being paid to the recycling of clothing that is no longer used, there is still considerable opportunities for implementing various improvements in this segment of the application of the circular economy concept. In addition to clothing, recycling must include numerous other types of textile products, such as medical textiles, textiles used in cars, pieces of furniture, etc. The increasing production of so-called smart textiles presents numerous challenges related to the recycling of products made from these materials. A large number of different composite materials are used in these products, the recycling of which represents a great challenge and is very complex [14]. Managing textile

products containing composite materials at the end of their life is a significant challenge. The methods used today, based on their disposal in landfills and different types of recycling, have numerous limitations, which must be overcome. Innovative approaches must ensure the integration of this type of textile products into the circular economy, in order to maximize their value and minimize negative impacts on the environment.

Within the framework of the circular economy, the greatest attention is paid to recycling, reuse and repurposing of natural and synthetic textile waste, using mechanical and chemical methods of recycling [7]. In the case of natural materials, mechanical recycling is suitable for textile products made from cotton fibers, while chemical recycling is suitable for products made from silk and wool fibers. Textile products made from synthetic materials are suitable for both types of recycling, with mechanical recycling being more suitable for products made from polyester fibres. An increasing number of textile companies are using materials obtained by recycling plastic bottles in their production, thereby reducing environmental pollution and dependence on polyester fibers.

The development of the concept of fast fashion, which enables manufacturers to make high profits and increase the number of products sold, has resulted in extremely significant negative impacts on the environment. In the period from 2010 to 2020, the production of fashion products increased by more than 100%, which led to a significant increase in the consumption of raw materials and the creation of large amounts of waste. This negative trend is additionally contributed by the fact that over 50% of fast fashion products cease to be used within a maximum period of one year after their purchase [15]. The concept of fast fashion, which emphasises the purchase of new products and the abandonment of fully functional products, has an extremely negative economic and environmental impact, the reduction of which must be one of the most important goals of the circular economy.

About 90 million tons of clothing are produced annually on a global scale and are discarded for various reasons. Almost 70% of this clothing can be reused, with the percentage of its recycling in 2021 being less than 10% [16]. Based on the above data, the importance and role of textile recycling in the concept of circular economy and the functioning of modern society can best be seen. In addition to extending the life of textile products, their recycling at the end of the period of use is an element that can significantly reduce the negative consequences for the environment.

The quantity of recycled textile products is influenced by a variety of different factors, the most important of which are the type, quality and quantity of waste as well as the legal requirements for the management of textile waste and its recycling. The lack of legal regulation is one of the basic and most important factors affecting the low recycling rates of textile products. There are a large number of factors that negatively affect the application of the circular economy in the management of textile waste and its recycling. Technological development, recycling costs, understanding of market dynamics, business models, public awareness, and the lack of standardized policies and regulations can be singled out as factors that have the greatest negative impact on the application of the circular economy concept in this area [15].

Increasing the percentage of textile products that are recycled at the end of their life is one of the elements that can significantly reduce numerous negative consequences for the environment. The amount of textile waste that is disposed of in landfills represents a

significant burden on the environment, while a large part of this waste can be recycled and reused at relatively low costs. Innovations in materials from which textile products are made, as well as the development of new techniques for recycling and reuse, which are based on the use of modern technologies, can have a significant impact on the increase in the amount of textile waste that is recycled [17]. Scientific research and the development of new knowledge can significantly influence the application of the circular economy in all segments of the textile industry. The recycling and reuse of materials after the disposal of textile products must be the subject of further scientific research in order to ensure appropriate improvements and innovations in this area. Research in the field of textile recycling in the circular economy must be aimed at reducing negative impacts on the environment and encouraging sustainable and environmentally friendly practices.

6. CONCLUSION

The recycling and reuse of materials after the disposal of textile products must be the subject of further scientific research in order to ensure appropriate improvements and innovations in this area. Recycling and reuse of textile products enable a significant reduction in the amount of textile waste disposed of in landfills. In this way, numerous positive effects are achieved, such as reducing the amount of waste disposed of in landfills, reducing the amount of raw materials used for the production of textile fibers from which materials are made, and reducing the costs associated with waste management.
The circular economy represents an approach in which emphasis is placed on all segments of the life cycle of textile products, from the production of the raw materials from which they are made to the end of their use. Within this concept, special emphasis is placed on different ways of recycling and reusing textile products and the materials from which they are made. The application of the circular economy enables a significant reduction of the waste disposed of in landfills. Due to the large negative consequences associated with the disposal of end-of-life products, textile recycling plays an extremely important role in the circular economy concept. As one of the basic prerequisites for greater use of recycling of textile products, the definition of global standards and national laws, with the help of which the obligation to recycle these products would be imposed on manufacturers, is highlighted.

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