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FOREWORD

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

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

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

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

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

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

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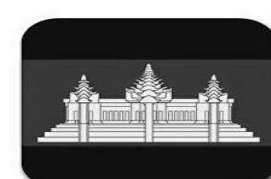
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TEXTILE WASTE MANAGEMENT AND MATERIAL INNOVATION: A NEW PERSPECTIVE

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ABSTRACT

This review paper synthesizes research on textile waste management, sustainability, and innovative reuse of textile materials, with a focus on the Republic of North Macedonia. Over the past fifteen years, studies have examined the generation, classification, and treatment of textile waste, revealing its environmental and economic implications. The analyses cover pre-consumer, post-consumer, and industrial waste, providing valuable insights into their composition and management practices. Findings indicate that pre-consumer cutting waste dominates in the Macedonian apparel industry, primarily consisting of cotton and cotton-blend fabrics. Although up to 95% of this waste could be recycled, most still ends up in landfills due to inadequate infrastructure, limited resources, and weak regulations. Comparative research highlights the gap between local and European circular economy practices.

Recent investigations have developed new methods for quantifying waste and explored converting textile waste into sustainable insulation materials. These innovations reduce landfill dependence and create new eco-market opportunities. Overall, the research illustrates a shift from disposal toward resource valorization and circularity, reinforcing the importance of innovation, education, and public-private collaboration for a more sustainable textile industry.

Keywords: textile waste, sustainability, recycling, circular economy, insulation materials.

INTRODUCTION

The global textile industry has become one of the fastest-growing sectors, yet it remains a major source of environmental pollution due to waste generation, chemical usage, and unsustainable production models. In the context of the Republic of North Macedonia, where the apparel industry is a vital economic sector, the problem of textile waste management is particularly pronounced.

Textile waste is classified into three groups (Maksimov S. et al., 2022):

- Textile waste generated before use (*pre-consumer*) - it represents the waste of the production which occurs in the processing of fibres while forming yarns, fabrics, knitted and non-wovens, textile products, including residues when cutting the materials (pattern waste, damaged fabrics and end-of-rolls wastes),
- Textile waste generated after use (*post-consumer*) - it represents all types of clothing or textiles for households which has no longer usability value for consumers and is thrown away, regardless of whether it is poured, damaged, superficially or simply out of fashion trends,
- *Industrial textile waste* - the waste generated from textile manufacture for commercial or industrial purposes, including textile waste from the manufacturing of carpets and curtains and hospital waste.

Managing such waste is a complex issue largely determined by the production technologies in use. Since entirely waste-free production technologies do not yet exist, the re-utilization of post-industrial waste must be regarded as a fundamental concept in textile waste management. The accumulation of textile waste results in a loss of resources and energy, creates environmental challenges, and leads to

additional expenses for collection, transport, and disposal. Although contemporary waste management systems consider landfilling the least desirable option, it continues to dominate textile waste management practices.

1. COMPREHENSIVE REVIEW OF RESEARCH ON TEXTILE WASTE AND SUSTAINABILITY

The focus of this paper will be on studies related to the situation of textile waste, its quantity and quality, and its management in the Republic of North Macedonia, as well as on textile waste management practices in other countries.

1.1. Quantity and quality of textile waste in the Republic of North Macedonia

Over the past fifteen years, several studies have emerged on pre-consumer textile waste and its management in the Republic of North Macedonia. The initial phase of these studies are focused on identifying and classifying the textile waste in R. N. Macedonia. The studies classified textile waste into pre-consumer and post-consumer categories, with emphasis on pre-consumer waste such as cutting scraps, selvedge waste, and defective materials. Early studies (Jordeva et al., 2013; 2014) provided one of the first detailed qualitative and quantitative analyses of pre-consumer textile waste in Macedonia. These investigations revealed that a significant portion—often exceeding 10% of the total fabric used—was lost during the cutting and sewing stages.

In the study (Jordeva et al., 2015) a characterization of textile waste by type and raw material composition was carried out. The authors found that in the Republic of North Macedonia, cutting waste predominates, consisting mostly of cotton or cotton-blend materials (cotton/polyester). The results of the study were obtained through a questionnaire distributed to top managers of Macedonian textile companies. The main conclusion of this research is that almost all textile waste ends up in landfills, with only about 5% being reused. The main reasons for this situation include the small number of workers available for waste sorting, lack of infrastructure, and limited financial resources. The paper provides a foundation for improving textile waste management and highlights the need for systematic collection and recycling, especially considering that 95% of textile waste can be recycled. Another study, (Jordeva et al., 2018) focuses on accurately assessing the amount of waste generated during garment cutting (pre-consumer waste). The conclusion shows that the average annual amount of cutting waste in the Republic of North Macedonia between 2009 and 2014 was approximately 3,377 tons per year. Even though the quantities remained relatively constant, nearly all this waste ended up in landfills, meaning it was not recycled. One of the more recent studies, (Maksimov et al., 2022) titled develops a new methodology for determining the quantity of cutting waste directly at the point of generation—namely, within garment manufacturing companies. The methodology proposed introduced standardized procedures for measuring the quantity and type of waste produced during the cutting process, enabling better control and monitoring at the industrial level. The research was conducted in three companies, and the results show that the proposed methodology is applicable and can help obtain accurate data on the quantity of cutting waste produced. This systematic approach helped establish a foundation for future waste reduction strategies and sustainable material planning.

1.2. Textile waste management practices

In Europe, textile waste is mainly eliminated through incineration, as landfilling recyclable materials is prohibited (P6_TA-PROV(2007)0000). France and Germany have largely closed landfills, while the UK still disposes of about 70% of textile waste this way. Most textile waste in these countries comes from households, with minimal industrial waste, (Microsoft Word - Report Ouvertes Project June2005.doc). Large-scale apparel production is concentrated in developing countries such as Turkey, Lithuania, and South Africa, selected for comparison with Macedonia due to similar GDP levels (List of countries by GDP (PPP) per capita - Wikipedia). Turkey, one of the top global textile exporters, significantly contributes to global recycling efforts (World trade report 2011). Its textile industry shows rapid growth, surpassing EU averages in several indicators (Milašius R., et. al., 2014). In 2008, Turkey recycled or sold most of its textile waste, with

only 16% landfilled (Altun S., 2012). Lithuania's waste consists mainly of natural and blended fibers, with about half ending up in landfills (Kazakeviciute G., et al., 2008). In South Africa, most textile waste is landfilled due to limited technology and low disposal costs (Larney M & Aardt AM.) Grasso (1995) highlighted the critical importance of properly sorting and packing apparel waste, noting that it must be clean and free of contaminants to transform it from garbage into a valuable resource. Furthermore, he observed that bailing apparel waste, rather than packing it in boxes or bags, enhances its suitability for sale.

As the understanding of textile waste grew, subsequent research (Maksimov S. et al., 2022; Zhezhova S. et al., 2022) examined the management practices implemented by apparel producers in North Macedonia. These studies evaluated the collection, sorting, storage, and disposal methods used by local factories, revealing substantial gaps in both organizational and legislative frameworks. The results indicated that textile waste management in North Macedonia was largely unregulated, with most waste being disposed of in municipal landfills without proper sorting or reuse. The research also highlighted the lack of awareness among factory managers regarding the economic potential of waste recycling and reuse. These findings underscore the necessity of a structured national strategy for textile waste management, emphasizing collaboration among government, academia, and industry. The papers proposed the establishment of regional waste collection centers, incentives for recycling initiatives, and the integration of waste management education into technical curricula.

1.3. Attitudes and awareness toward waste management

A parallel line of research, represented by Attitudes Towards Managing Post-Industrial Apparel Cuttings Waste (Tomovska E. et al., 2017), explored the behavioral and managerial dimensions of waste handling in the textile industry. Surveys conducted among textile company managers revealed that economic considerations, lack of recycling infrastructure, and limited access to innovation were major obstacles to adopting sustainable practices. These insights highlight the importance of continuous education, capacity-building, and the dissemination of best practices across the textile sector. The authors recommend developing public-private partnerships and implementing pilot recycling projects to demonstrate the feasibility of sustainable textile waste management.

1.4. Innovative utilization of textile waste

The second focus of this research is on papers that propose innovative materials made from textile waste. In this context, the study titled 'Application of Apparel Cutting Waste as Insulation Material' is particularly noteworthy because it "Application of apparel cutting waste as insulation material" (Jordeva S. et al., 2014) is interesting. The research team demonstrated that textile waste could serve as a viable alternative to conventional insulation materials. The study designed new insulation material (for partition walls in buildings) and conducted tests to evaluate its physical properties, thermal conductivity, and potential to replace traditional insulation materials. The thermal conductivity coefficient (λ) of the new product was compared with standard insulation materials. The results show that the thermal conductivity coefficient $\lambda = 0.05198-0.06032$ W/mK. The material demonstrates sufficient mechanical and thermal stability for use as insulation. This indicates a high potential for utilizing a significant portion of textile waste instead of landfilling it. The research paves the way for the practical, value-added use of textile waste and proposes a circular approach: cutting \rightarrow waste \rightarrow reuse \rightarrow insulation. Further studies, (Trajković D. et al., 2017) and (Jordeva S. et al., 2019), confirmed the excellent thermal and acoustic properties of recycled polyester materials. Laboratory tests showed that these insulation panels provided comparable or even superior performance to synthetic insulation products, with added environmental benefits. Moreover, the works presented at international conferences (Jordeva S. et al., 2015; 2016) investigated the fire resistance, sound insulation, and structural characteristics of textile waste composites. The development of eco-friendly insulation materials not only contributes to waste reduction but also opens new markets for sustainable products in the construction sector.

1.5. Contribution to sustainable development and circular economy

The evolution of research in this field reflects the broader transition from mere waste disposal to resource valorization, which lies at the heart of the circular economy concept. Over the years, investigations have progressed from identifying and quantifying textile waste to developing sustainable materials and promoting eco-design and waste minimization principles. Recent studies have positioned the Macedonian textile industry within the framework of European sustainability policies, aligning local efforts with global environmental goals including the EU Green Deal and the United Nations Sustainable Development Goals (SDGs). This interdisciplinary research-integrating textile technology, environmental science, and industrial engineering-has established a foundation for incorporating circular economy principles into textile production systems. The findings have contributed to advancing both regional and international understanding of sustainable textile waste management and have inspired new research directions aimed at developing innovative materials, optimizing production processes, and embedding waste reduction within corporate and industrial strategies.

Based on this and other analyzed research, two summary tables were created: one presenting scientific and statistical studies on textile waste in Macedonia, and another comparing regional and European trends. Table 3 presents the main conclusions and trends.

Table 1: Overview of scientific research and data on textile waste in R. N. Macedonia

No.	Research / Source	Year	Main Findings	Conclusions
1	Current State of pre-consumer apparel waste management in Macedonia	2015	The research was conducted through a questionnaire in 120 Macedonian apparel manufacturers.	Disposal in landfills is the dominant waste management practice.
2	Qualitative and quantitative analysis of the pre-consumer textile waste in North Macedonia	2022	Investigation of the textile waste quantity and quality as a pre-condition for its further management	Domination of the apparel cutting waste composed of cotton and synthetic fibers, average of 1.42 kg per capita of pure pre-consumer textile waste generated annually.
3	Ministry of Environment and Physical Planning (MoEPP) – Waste Management Report	2023	Macedonia annually generates over 8,000 tons of textile waste.	The recycling system is in its initial phase; 90% ends up in landfills.
4	Circular Economy Project (UNDP – North Macedonia)	2023	Analysis of possibilities for recycling and reuse.	Potential for 20–25% utilization through the introduction of selective collection.

Table 2: Comparative Data: Textile waste and recycling in the region and the EU

Country / Region	Year	Generated Quantity (tons)	Recycling / Reuse (%)	Source / Notes
Macedonia	2023	~8,000	< 5%	MoEPP, UNDP (2023)
Bulgaria	2024	> 100,000	2%	novinite.com (2024)
Romania	2024	~160,000	up to 10%	green-forum.eu (2024)
Serbia	2024	~90,000	< 5%	ekapija.com (2024)
Greece	2023	~120,000	5–7%	Hellenic Recycling Org.
EU average (27 countries)	2022	6.94 million	15%	EEA Report (2022)

Table 3. Main conclusions and trends

Category	Macedonia	The Region	The EU
Sorting infrastructure	Insufficient; no separate collection	Similarly low (partially developed in Romania)	Well developed in most countries
Recycling capacities	Minimal, limited to mechanical processing	Limited	Advanced systems (reuse, chemical recycling)
Legal framework (EPR)	In preparation	Early implementation (Romania)	Active in most countries
General trend	Need for systematic waste management	Similar challenges across the Balkans	Moving toward a circular economy

CONCLUSION

This review demonstrates the growing importance of sustainable textile waste management within North Macedonia and beyond. The analyzed studies in this paper have built a solid scientific foundation for the transition from traditional waste disposal toward a circular economy. The studies have revealed that the majority of textile waste remains unrecycled and underutilized, despite its high potential for reuse in insulation and other eco-material applications. The implementation of standardized waste quantification methodologies and the promotion of awareness across industry stakeholders represent significant steps forward. Future research should focus on scaling up recycling technologies, integrating life-cycle assessment into production planning, and establishing national policies to support sustainable textile practices. This evidence collectively underscores the essential role of innovation, education, and cross-sector collaboration in achieving long-term environmental resilience and industrial sustainability.

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