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Faculty of Industrial Design and Business Management

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TOPOLOGY BASED 3D MODELLING OF TEXTILES WITH MACHINE EMBROIDERY STITCHES

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***Abstract**. Beyond decorative purposes, embroidery can be used for many applications, e. g. for smart textiles, for load-adapted fiber-plastic composites and also for healthcare based on free standing lace embroidery. For the engineering design of such products, it is necessary to investigate the geometry at the yarn level. This paper presents an algorithm, corresponding data structures, and their implementation in software for the design of the 3D geometry of the embroidered textiles which is based on the CAD data used for the production process. The textile structure is created with available software tools and converted into an open XML-based format. The geometry of sewing threads is computed based on a topology-based model and imposed in the structures as an additional system. The final embroidered structure can be exported at yarn (mezzo) level in various CAD and FEM formats for computations, which significantly shortens the designing process.*

***Keywords:** embroidery, sewing, stitches, mezzo level, yarn level, modelling, geometry, FEM*

1. INTRODUCTION

The embroidery process has traditionally been used for decoration purposes. Since the end of the 19th century, hand embroidery has been largely replaced by machine embroidery. In addition to its decorative purposes, it enables the integration of functional elements such as wires and sensors, making it possible to produce smart textiles. Furthermore, it serves as a versatile tool for creating load-adapted reinforcements for use in fiber-reinforced plastics [1] Because of the significant design freedom available when creating embroidered free-standing structures, there is also great potential for medical products.

These specialized products require meticulous and intricate engineering designs to meet the prescribed functionalities and constraints relevant to their intended applications. Numerical methods are widely used to perform structural simulations. The most commonly used numerical methods, such as the Finite Element Method (FEM), require detailed information about the 3D geometry of the textile structure, the thread geometry and their positions in the textile structure generated by weaving, knitting, braiding, or any other similar textile generation processes. This forms the pre-processing data, which is subsequently used to perform the numerical simulation by FEM. The current research is focused on developing a method for generating 3D geometry starting from the embroidery data, producing the thread geometry, and ending with the desired 3D geometry in suitable file formats for FEM simulations.

2. STATE-OF THE ART

The modeling of textile structures is more complicated than the modeling of objects represented by rigid bodies. This is due to the fact that the textile structures are built of assemblies with several levels of grouped single fibers or continuous filaments with very low bending rigidity. While there are more than 20 CAD programs capable of generating the geometry of woven fabrics [2], only one of them,*Wisetex*, considers the mechanical properties of the yarns and computes the minimum of the potential energy of the yarns in order to obtain correct relaxed geometry of the fabrics [3, 4]. The majority of the models typically start with a geometrical model. In contrast, Kyosev [5] distinguishes between geometrical and topology-based models, defining the topology-based models as such, where only the “type of the interlacement” is preserved, but the exact geometry of the yarn paths is not explicitly defined. On the other hand, geometrical models define the complete yarn paths (and not only the interlacement points) mathematically. In fact, the textile structures are defined by a lot of contacts and a pure analytical description of the geometry of the yarn paths is not possible. Thus, any explicit description of the yarn path as an analytical function or its delivery by approximation or fitting will remain a “topology” model and not a mechanically correct geometry. The methodology of the topology-based modeling is explained for braided and knitted structures [5, 6] and is applied to different classes of sewing stitches. The main idea involves defining several key points and connecting them. This approach is also applied to woven structures [7–11], warp and weft knitting with a plane main surface [10–14], morphing into 3D geometry [15], crocheting [16], and, importantly, for computating yarn consumption of the sewing stitches [17]. The modeling of single stitch types is covered as a part of the regular course of university education by Kyosev [18].

On the other side, the modeling of embroidery stitches is a lesser-reported topic. The modified type of embroidery, named Tailored Fiber Placement (TFP) where thicker tows of high-performance fibers are placed in specific paths and fixed through over-stitching is well investigated at the level of the tow geometry [19], concentrating on the waviness of the structure [20]. For engineering applications, the placement of the reinforcement yarn is important for the stiffness and strength calculations of the complex parts but modeling of the sewing threads is neglected. This is due to the fact that they are mainly used for temporary fixation of the tows until they get consolidated by the matrix component. Changes in geometry after stitching are crucial for all applications [21], but they are investigated only experimentally.

Another growing application area of embroidered textiles is the so-called e-textiles (from electro-textiles), smart textiles [22, 23], or probably the most accurate, but seldom used name for such products would be “sensorized garments” [24]. An example of the integration of embroidered parts as sensors is for the non-invasive inspection of bedridden patients [25, 26]. The conductive materials necessitate special treatment for the integration and processing and some practical steps in the production of embroidered textiles with them are reported in Sofronova et al. [27]. The embroidery allows fully integrated production of textile sensors based on conductive yarns, using them as connection wires and as wires for fixing and integrating ready-made (non-textile based) electrical components on the textile structure [28]. Nolden et. al [29] reported the development of flexible and functional sequins using subtractive technology and 3D printing so that these can be integrated over textiles using embroidery. Normann et. al [30] applied the TFP technology for the creation of textile batteries, placing parallel cornering or meandering lines. The same team reported the application of embroidery for the production of smart gloves [31]. For all these smart applications the information regarding the position and orientation of the sewing threads can be used for computing the electric resistance and designing the circuits in a similar way as reported for textile structures by Kyosev [32], provided that the geometry of the stitches is available.

Beyond the mentioned application areas, embroidery holds significant promise for implantable medical products, particularly in the context of mesh implants, artificial ligaments, and tendons. The primary distinguishing feature is the utilization of biocompatible, medically approved thread materials, which must be used. In this case, a water-soluble embroidery fabric is typically completely removed, resulting in the creation of a self-supporting textile structure. This type of embroidery is based on etching techniques, as it has long been used for home textiles, curtains, and clothing. In the case of medical applications, this approach is called “medical lace embroidery” [33, 34].

The process of sewing or embroidery is not considered for modeling at the level of the stitch building, and as a result, papers related to this topic will be not considered. The process becomes important if the geometry of the single stitching place has to be extended and its accuracy improved.

Summarizing the overview, the authors found no suitable tool for the modeling of embroidery structures with the fabrics at the mezzo (yarn) level. As a result, the workflow for the modeling process is presented in this paper.

3. METHOD

The embroidered structure can be considered as an assembly of two sub-structures:

- basis structure (woven, knitted, nonwoven, paper),
- long chain of stitches following defined embroidery program.

In reality, the basis structure is created before the stitching process and the natural way for modeling will be to follow the reality. The fabrics can be modeled independently and created as 3D geometry before the stitching process. For fabrics, there are several tools available such as *Wisetex* for Woven structures [8,29], *TexGen* for woven, *Python* scripting for general type of structures [30,31], *Texmind* for warp knitted and braided structures [32,33], and for the case of using Python scripting for any type of structures, the free library pytexlib [34] can be used. All these tools can be used for definition of the yarn paths, and the 3D files can be imported and converted to open XML format using TexMind Exporter.

The sewing stitches of class 300, which are used often used as embroidery stitches are modelled using keypoints (Eq. 1-7) as described in [5] (Fig.1).

$$A = [-0.5t_{in} - 0.5d_{up} \quad h + 0.5d_{up} \quad 0] \tag{1}$$

$$B = [-0.5t_{in} \quad h \quad 0] \tag{2}$$

$$P_1 = [-0.5t_{in1} \quad h_c + h_1 \quad 0] \tag{3}$$

$$P_2 = [0 \quad h_c - 0.5d_{up} - \Delta \quad 0] \tag{4}$$

$$P_3 = [0.5t_{in1} \quad h_c + h_1 \quad 0] \tag{5}$$

$$C = [0.5t_{in} \quad h \quad 0] \tag{6}$$

$$D = [0.5t_{in} + 0.5d_{up} \quad h + 0.5d_{up} \quad 0] \tag{7}$$

During the embroidery process, the stitches change their orientation, which indicates that the arc CD (Figure 1) which describes the upper thread has to be oriented in the direction of the next stich. The same is valid for the bottom thread.

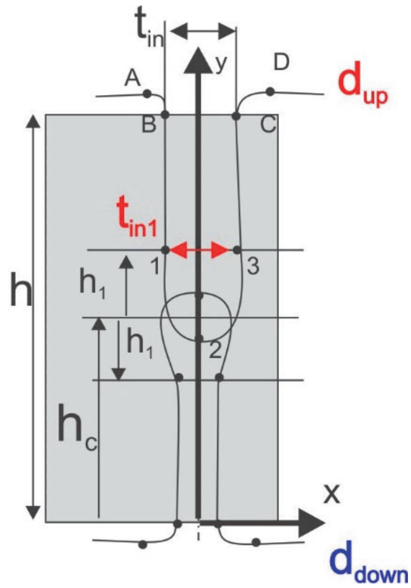

Figure 1. Geometrical model of single stitch (without side rotation of the threads) [5]

In order to orient the yarn geometry properly, the list of the coordinates

P1(x,y,z); P2(x,y,z); P3(x,y,z); P4(x,y,z);…

of the stitch positions, where the needle will enter the material is required. This list is loaded from the file, generated from the punching software, after some conversion to more readable text-based (comma-separated value) format. The coordinate of the current point P_i determines the global coordinates for the placement of the interlacement (stitch) of the bottom and upper threads (Point 2), based on Figure 1, the vector to the next point $\overrightarrow{P_i P_{i+1}}$ determines the orientation of the points 3-C-D of the thread, and the backward vector $\overrightarrow{P_i P_{i-1}}$ determines the orientation of the initial path of the thread (Points A-B-1, Fig. 1)).

The complete procedure is implemented in *C++* within the Software *TexMind Stitcher*, which has the advantage of having integrated 3D-Viewer for textile products and exports to various FEM formats.

3. RESULTS AND DISCUSSION

The algorithm was tested with a sample of a flower, demonstrated in Figure 2. The embroidery design was created using conventional punch software (Tajima DG16 by Pulse) and converted into the csv-format using a Python script. The 3D visualization of stitches over ground textile (Figure 3 (A)) poses significant challenges, because of the alternation of areas with almost straight threads between the stitches, where the normals and binormals of the yarn axis curve are undefined, followed by the stitch themselves, characterized by threads with a very low curvature radius.

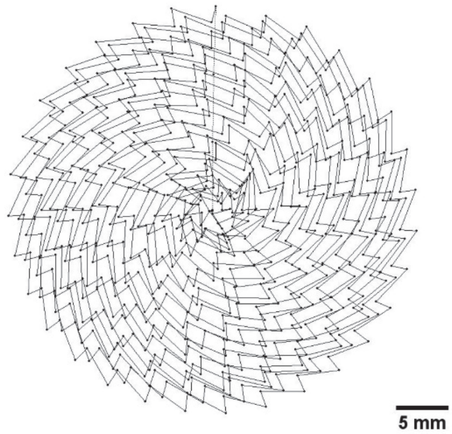

Figure 2. Punched images of a profile "flower" for stitching used as a test data

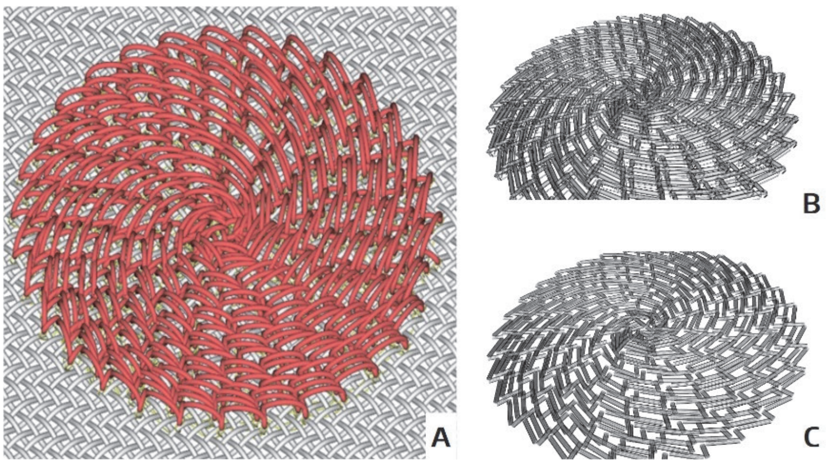

Figure 3. (A) 3D simulated results of the stitching yarns and the ground textile fabrics from Figure 2;
(B) Reducing the complexity of the 3D representation by removing the arcs;
(C) Option of visualization with connecting lines only.

For several applications like stiffness calculations of the resulting product the orientation of the connecting parts is sufficient. For these cases, but also for classical embroideries as in the "flower" shown as an example, the 3D representation of the stitches can be simplified by removing parts of the connecting arcs (Figure 3 (B)) or removing the complete stitch part (Figure 3 (C)). The model consists all points of the stitches and these simplifications are produced by skipping some of the available data as an option only so that principally all these variants are available for computations.

For comparison the design was machine-embroidered onto non-woven fabric employing polyester yarn, as illustrated in Figure 4.

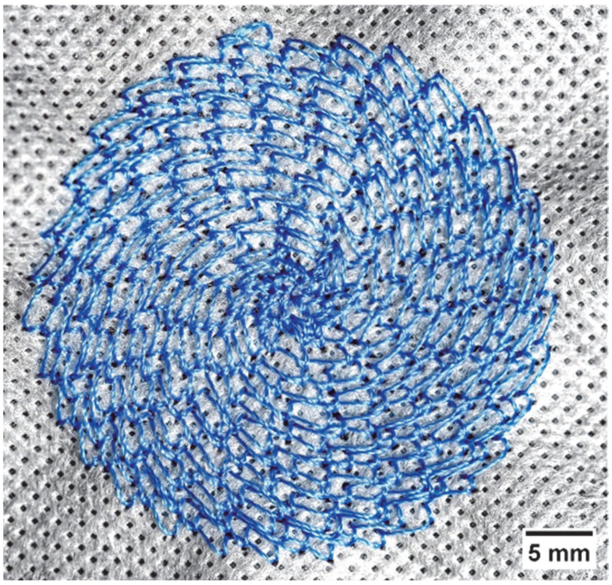

Figure 4. Embroidered test pattern “flower”

4. CONCLUSIONS

This paper provides a literature overview regarding the modeling of textile structures and stitches at the yarn level. As there are no tools and methods available for the creation of 3D models of the stitched structures, the authors have created such a model, based on a C++ program, using the available *Texmind Viewer* for visualization of yarn-based structures. The created tool allows the reading of the coordinates from the text file and the creation of 3D geometry of the stitches. This geometry can be superimposed on the ground fabrics' geometry and exported as a complete set for advanced FEM or CFD computations.

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COMPARISON OF TOWELS PRODUCED WITH SUSTAINABLE FIBRES IN TERMS OF WATER ABSORPTION AND FAST DRYING PROPERTIES

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***Abstract**. Recent developments have seen an increase in the use of sustainable fibers to replace cotton fibers in terry fabrics, particularly textiles that require exceptional water absorption and fast drying qualities. The properties of towels produced from these fibers are meticulously combined with the properties of towels produced from 100% cotton fiber. In this research, the water absorbency and quick drying properties of towels produced from yarns produced by combining cotton fibers with modal, lyocell and cellulose acetate fibers were investigated and comparisons were made with towels produced from yarns containing only cotton fibers. Various factors such as vertical capillarity, surface water absorbency, drying rate and water vapor evaporation rate were examined and compared with the sample containing 100% cotton fiber in the yarn composition. The findings highlighted that samples containing lyocell and cellulose acetate fibers exhibited superior absorbency and drying properties compared to their 100% cotton fiber counterparts. Therefore, this study underlines the feasibility of replacing cotton fibers with sustainable alternatives such as lyocell, modal and cellulose acetate in the field of terry cloth production. The study seeks to develop terry cloth fabrics possessing superior water absorption and rapid drying characteristics. The main objective of this study is to contribute to the development of terry fabrics with superior water absorption and fast drying properties. Therefore, it emphasises the need to promote the use of sustainable alternatives to replace cotton fibres in order to achieve a balance between sustainability and performance in the textile industry.*

***Keywords:** sustainable fibers, towel, water absorbent, water evaporation, sustainability.*

1. INTRODUCTION

The evaluation of water absorption and fast drying properties in towels is a topic of great importance not only for the textile industry, but also for the wider context of consumer welfare. Towels are an essential part of our daily life and play a crucial role in terms of personal hygiene and comfort. Understanding and measuring the extent to which towels are successful in efficiently absorbing moisture and drying quickly is crucial for both manufacturers and end users. Hometech towels have vital features such as fast drying and impressive water absorption. The quick-drying feature facilitates the rapid evaporation of moisture from the towel surface. This allows the user to reuse the towel immediately, which is important for hygiene. In addition, the high water absorption feature allows the towels to absorb water quickly and effectively, providing a comfortable experience by effectively drying the skin after showering or bathing. Overall, these features emphasize the importance of hometech towels for personal hygiene and make them a pragmatic choice. This study aims to shed light on the factors affecting water absorption and drying rates in towels produced from sustainable fibres and to scientifically evaluate these critical properties. In this way, we aim to provide valuable information that can inform the development of towels with better performance and contribute to a more pleasant and hygienic user experience.

Some of the previous studies on the subject can be summarised as follows.

Ozbahar examined the performance properties of fabrics containing pile yarns with different fiber types. In the research, towels produced from yarns containing organic cotton, silk, cashmere, Microcotton®, lyocell (Tencel®), viscose (EcoVero and Viloft) fibers were analysed. It has carried out a series of tests in accordance with the relevant standards in order to determine the performance characteristics of the towel fabrics produced. Tests consist of weight determination, water immersion, water and air permeability, water evaporation rate, drying rate, vertical capillarity and hardness. The porosity of terry cloth was also calculated theoretically. After statistical analysis of experimental and theoretical data, it was determined that viscose based Viloft fiber exhibited the best performance [1].

The water absorption and air permeability properties of towels made from cotton, bamboo-cotton and micro-cotton yarns, such as absorbency and capillary properties, were investigated by Eren et al [2]. As a result of their studies, they found that terry towels made from different fibre blends had different water absorption and air permeability depending on the fibre type [2].

Askın conducted the towel weaving process by varying the weft density and pile height, which are critical parameters for terry fabrics' structural quality. The resulting terry fabrics underwent a range of comfort and performance tests, including air and water vapor permeability, thermal properties and absorbency. The obtained results were analysed and interpreted using statistical methods. She stated that the parameters she tests are primarily affected by weft density and pile height [3].

Singh and Behera conducted a comprehensive study of the water absorption theory in terry fabrics, encompassing the influence of fabric properties such as pile height, weft and warp density, yarn twist, and yarn count, on both static and dynamic water absorption. Their analysis also included process factors such as washing, drying, and finishing processes that affect water absorption. The researchers meticulously organised and analysed relevant research studies [4].

Sekerden conducted a comparative analysis of the physical properties of towels made from cotton and a blend of bamboo and cotton pile yarns. The study investigated the impact of pile yarn type and height on the mechanical properties of towels, including absorbency, hardness, and abrasion resistance, using analysis of variance. The sink test was employed to evaluate absorbency, while the abrasion resistance was gauged using mass loss calculations. Stiffness values were determined using bending tests. The measurements were analysed using an ANOVA test. The results demonstrate the superiority of bamboo pile yarn towels compared to 100% cotton towels, with the exception of abrasion resistance [5].

2. EXPERIMENTAL PART

In our study, we used towels produced using the three-weft towel weaving process. The weft and ground warp yarns of the towels consist of cotton only, while the pile warp yarns consist of a blend of cotton, modal, lyocell and cellulose acetate fibres in certain proportions. The construction information of the woven terry fabrics used is given in the table below.

Table 1
Construction information of fabrics

Pile warp thread (Ne)	Ground warp thread (Ne)	Weft thread (Ne)	Gsm (gr/m^2)	Weft density (weft/cm)	Warp density (warp/cm)
12/1 Cotton 60% - Lyocell 40%	20/2 Cotton	16/1 Cotton	600	15	12
12/1 Cotton 60%- Cellulose Acetate 40%	20/2 Cotton	16/1 Cotton	600	15	12
12/1 Cotton %60- Modal 40%	20/2 Cotton	16/1 Cotton	600	15	12
12/1 Cotton %100	20/2 Cotton	16/1 Cotton	600	15	12

After the sample fabrics were conditioned under standard atmospheric conditions (20^{o}C, 65% RH), the following tests were carried out.

Table 2
Tests performed and standards taken as basis.

Test name	Relevant standard or basis of study
Vertical capillary wetting (capillarity) test	DIN 53924 - Standard Test for Wetting Water Velocity of Textile Fabrics [6]
Drying rate detection	Fourt and Coplan [7,8]
Water evaporation rate	Fanguiero et al. [9]
Surface absorbency test	ASTM D 4772-97 - Standard Test Method for Surface Water Absorption of Terry Fabrics [10]
Test of the sinking time	TS 866 - Absorbency of Bleached Cotton Textile Materials [11]

3. RESULTS AND DISCUSSION

3.1. Vertical Capillary Wetting (Capillarity) Test

The samples were prepared as strips of 25x100 mm in size, three each in the warp yarn direction of the fabric. The capillary wetting test of the prepared samples was carried out by the R&D Centre with the device which is the output of the TÜBİTAK project numbered 3189259 and the results obtained are given in the table below.

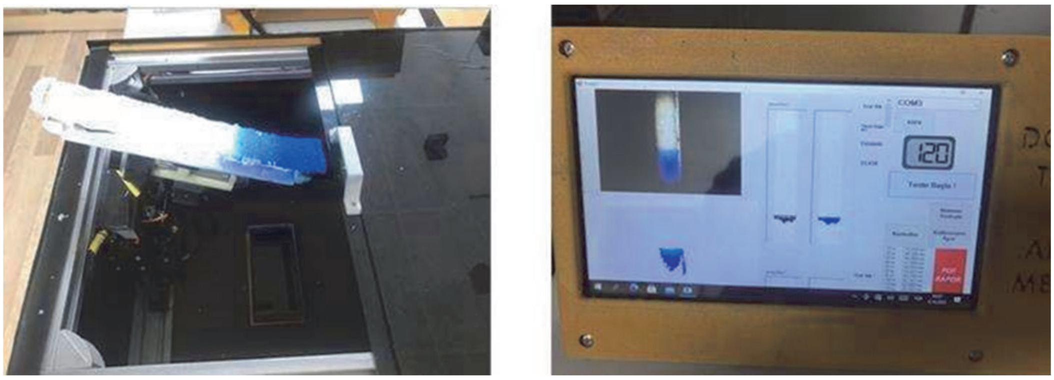

Figure 1. Vertical capillarity measurement device utilizing image processing technique.

Table 3
Capillarity test result rise amounts (mm)

Measurement time (second)	0.s	10. s	20. s	30. s	40. s	50. s	60. s	90. s	100. s	110. s	120. s
Cotton 100%	0	32.17	37.47	39.91	42.24	43.90	45.65	49.20	51.05	52.02	53.05
Cotton 60% - Modal 40%	0	36.79	42.34	46.62	49.34	51.92	54.31	59.32	62.10	63.94	64.72
Cotton 60%- Lyocell 40%	0	33.29	39.66	44.82	47.98	51.34	53.77	60.29	61.91	63.36	65.41
Cotton 60% -Cellulose Acetate 40%	0	34.60	40.98	44.58	47.69	50.22	51.73	56.94	58.03	59.76	61.08

3.2. Drying Rate Detection

The drying speed was determined using the Fourt and Coplan test as a reference [7,8]. To conduct the test, three samples measuring 80 mm in width and 160 mm in length were cut from the towels, and placed in a beaker of pure water for one hour until completely saturated. To conduct the test, three samples measuring 80 mm in width and 160 mm in length were cut from the towels, and placed in a beaker of pure water for one hour until completely saturated. At the end of one hour, the test specimens were removed from the water, squeezed gently and kept on the drying paper for two minutes for each surface to remove the remaining water. The samples were weighed on a precision balance and placed on the drying grids. Weights were taken for 3 hours, one at the beginning of each hour. moisture change was tried to be determined on it. The results obtained can be found in Table 4.

Table 4
Drying rate (%)

	Cotton100%	**Cotton 60% - Modal40%**	**Cotton 60% - Lyocell40%**	**Cotton 60% – Cellulose Acetate 40%**
End of 1st hour	7.16	7.47	5.35	12.28
End of 2nd hour	12.15	14.95	11.25	24.04
End of 3rd hour	17.10	22.04	16.88	35.43

3.3. Water Evaporation Rate

Water evaporation rate was determined according to the principle used in the study by Fanguiero et al. [9]. Three square samples of 8 cm x 8 cm were cut from each sample. The dry weights of these cut samples were determined using a precision balance and recorded as w_f. The dry samples were soaked with 30% of their dry sample weight in water and their weights were measured again and recorded as w_o [9].

The test specimens are allowed to dry on a drying grid. During the test period of 120 minutes, every 5 minutes, their weights are weighed on a precision balance and recorded as w_i [9]. At the end of each measurement, the evaporation rate of water is calculated using Equation 1.

$$\text{WER } (\%) = \frac{\text{wo}-\text{wi}}{\text{wo}-\text{wf}} * 100 \tag{1}$$

Table 5
Result of water evaporation rate (%)

Yarn content	**Dry weight (gr)**	**Wet weight (gr)**	**120 min endweight (gr)**	**Water evaporation rate(%)**
Cotton 100%	3.82	4.83	4.10	72.28
Cotton 60% - Modal40%	4.09	5.26	4.55	60.68
Cotton 60% -Lyocell 40%	4.41	5.65	4.98	54.03
Cotton 60% –Cellulose Acetate 40%	4.39	6.67	5.14	67.11

3.4. Surface Absorbency Test

ASTM D4772-97 - Standard Test Method for Surface Water Absorption of Terry Fabrics (Water Flow) was based on the standard [10]. The amount of water absorbed was calculated by Equation 2.

$$\text{Amount of Water Absorbed (ml)} = \frac{50 - \text{Amount of Water Collected in Reservoir (ml)}}{50} * 100 \quad (2)$$

Table 6
Results of surface absorbency test

Results of surface absorbency test (ml)	Cotton 100%	Cotton 60% -Lyocell 40%	Cotton 60% -Modal 40%	Cotton 60% -Cellulose Acetate 40%
Sample 1.	49	47	49	36
Sample 2.	49.5	47	49	37
Sample 3.	49	47	49	37
Mean	49.2	47	49	36.7
Standard deviation	0.2	0	0	0.5

3.5. Test of the Sinking Time

TS 866 - Water Absorption of Bleached Cotton Textile Products Determination of Properties standard, 75 mm x 75 mm samples to be used in the experiment were prepared with the help of a template. The sinking test is carried out by dropping the samples into 1000 ml of soft water in a 2000 ml beaker container from a height of 10 ± 2 mm. The test starts by starting the stopwatch when the fabric touches the water surface and ends by recording the value on the stopwatch when the fabric touches the beaker surface. For this test result, it was repeated for 3 samples taken from different parts of the fabric and the values obtained were averaged and calculated.

The sinking time of the fabric with high water absorbency is fast. Absorbency good if the sinking time is between 0-50 s, moderate if 50-100 s and poor if more than 100 s [11].

Table 7
Results of sinking time test

Sinking time test results (second)	Cotton100%	Cotton 60% - Lyocell 40%	Cotton 60%- Modal 40%	Cotton 60% Cellulose Acetate 40%
Sample 1.	7.22	9.1	7.89	6.04
Sample 2.	6.35	8.65	6.77	5.72
Sample 3.	6.81	7.86	5.7	6.42
Mean	6.79	8.54	6.79	6.06
Standard deviation	0.36	0.51	0.89	0.29

4. CONCLUSIONS

Today, increasing environmental problems and negative situations triggered by natural events due to global warming increase the level of environmental sensitivity in people.

With increasing environmental awareness, the need for biodegradable and sustainable products in the textile industry, as in many sectors, is increasing day by day.

Obtaining lyocell and cellulose acetate fibres with a sustainable production process using sustainable resources has brought them to the forefront as sustainable raw materials in textiles. Sustainable fibres can also be used in the production of towels that stand out with their high water absorbency and fast drying properties. With the tests we have conducted, we examine the effect of these fibres on these properties.

Based on the characteristics of the weaving process and yarn composition, we conducted multiple tests to assess the towels capacity to absorb water and dry. Our results demonstrate that the towels possess outstanding water absorption capabilities under specific conditions and can also dry incredibly quickly.

Our research has provided a crucial insight into how certain fibre blends can influence towel performance. These findings can provide guidance for designers and industrial applications when selecting materials for towel design and production.

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LASER TECHNOLOGY IN DENIM: THE CASE OF MAVI PRO EDITION

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Abstract. *Denim fabrics, with a history dating back to the 17th century, were initially used in the construction of pants preferred by workers in America. After the 1950s, influenced primarily by Hollywood stars and later by the atmosphere created by World War II, denim became a preferred material for various types of clothing worldwide. Denim garments are considered timeless pieces in the fashion industry, enduring through seasons and finding a place in the wardrobes of individuals with different statuses and lifestyles, characterized by a constant quest for novelty. Yet, the changing demands of fashion and evolving trends each season have shifted the focus in denim garment production towards various finishing and treatment processes, in addition to pattern-making and tailoring features. In the textile industry, almost all stages involve intensive resource consumption and waste generation, with finishing processes being the most pollution-intensive and toxic in nature. Considering the dimensions of the climate crisis and the impact of the industry on climate change, the use of alternative environmentally friendly methods for finishing treatments on denim fabric becomes crucial. An innovative approach to achieving a vintage look in denim, as an alternative to the traditional sanding process, is to utilize laser technology. A Turkish brand, Mavi, has adopted this method in its products, introducing a new approach to sustainable denim. The "Pro Edition Collection," is examined as a case study in this paper. When evaluating the men's collection, consisting of 14 pieces, it is observed that using laser technology to achieve a vintage appearance result in energy and water savings compared to similar collections. This approach also offers new design opportunities. In an era where the search for alternative methods and approaches for sustainable denim production is on the agenda, this research provides valuable insights for both the industry and researchers.*

Keywords: *sustainable denim, laser technology, sustainable innovation, denim collection.*

1. INTRODUCTION

The historical origins of denim fabric can be traced back to the 17th century. Denim fabric is characterized by a distinctive production process in which the warp yarns are intricately dyed with indigo, while the weft yarns remain in their natural, undyed state. Furthermore, the vast majority of denim textiles are primarily composed of cotton fibers. It was during the 19th century that denim fabric witnessed a significant surge in popularity, primarily within European nations, where it became the preferred choice for workwear due to the advent of mass production techniques. This trend later extended to the United States, where denim fabric found extensive use, not only within the realm of workwear but also in various other clothing categories. Today, denim fabrics have transcended demographic boundaries, becoming a ubiquitous presence in the wardrobes of individuals across diverse societal segments, securing a lasting niche within the ever-evolving landscape of fashion, spanning a wide array of product categories [1, 2].

Throughout the manufacturing process, the characteristic bluish hue of denim fabric is attributed to the prevalence of indigo-dyed warp yarns on its surface. Nevertheless, it is imperative to recognize that the evolution of denim fabric into a finished product is not solely contingent upon sewing techniques and pattern attributes, but is profoundly influenced by dyeing, printing, finishing, and treatment processes.

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These procedural facets culminate in the transformation of denim into a marketable commodity, thereby shifting the emphasis from its production to its presentation as a refined end-product [3].

In denim production, finishing processes pertain to the operations conducted on a fully assembled denim garment subsequent to the sewing phase. These intricate procedures entail subjecting the garment to specific washing procedures employing designated machinery, precise receipts, and techniques to eliminate sizing, introduce diverse color variations, and attain the desired textural attributes. In contemporary denim washing technology, the primary emphasis has transitioned towards the generation of novel color palettes and effects, a response to the dynamic proclivities of consumers and the pervasive influence of fashion trends [4].

Denim textiles represent a prominent domain of research within the textile industry. Originally fabricated with 100% cotton yarns, these textiles can acquire favorable attributes, including bidirectional elasticity, durability, and a capacity to conform seamlessly to the contours of the human body, through meticulous exploration of alternative fiber compositions [2, 5]. Furthermore, the advent of the 21st century witnessed the widespread popularity of slim-fit denim jeans among women, which consequently exerted a sustained influence on men's fashion as well [2, 6]. The production of such form-fitting apparel frequently necessitates the utilization of stretch fabrics, given that flexibility stands as a pivotal requisite for denim clothing. As a result, manufacturers of denim fabric and garments have earnestly directed their efforts towards the refinement and innovation of stretch fabrics [7].

Fashion, frequently intertwined with global political and societal transformations, has progressively shifted its emphasis towards the notion of comfort during the pandemic that swept across the world in 2019 and its subsequent repercussions. Additionally, significant influences on contemporary fashion encompass vintage aesthetics and nostalgia [8]. Denim garments, initially propelled into the limelight through cinematic portrayals, has sustained its resonance in the modern fashion milieu by embracing a worn appearance and evoking vintage sensibilities, aligning itself with current trends like streetwear and technology-inspired aesthetics [9]. The period of the pandemic has prompted a predilection among individuals for attire that is both comfortable and functional, consequently resulting in changes in both women's and men's fashion categories.

The creation of a worn appearance in denim products often involves the application of the "whiskering and sanding" technique. "Whiskering" denotes the practice of generating linear abrasions on specific areas of the garment, such as pockets and knees, where natural wear is anticipated, through the use of small abrasive tools. "Sanding" is the actual process whereby a portion of the indigo-dyed fibers is removed from the surface due to abrasion, resulting in a lighter appearance in the designated areas following the washing phase [10]. This method is manually implemented on semi-finished denim products using abrasive materials like sandpaper, resulting in the dispersion of airborne indigo particles and cotton fiber lint, thus giving rise to adverse consequences for both the well-being of workers and the environment [9]. Additionally, denim production necessitates a substantial consumption of energy and water, particularly during these processes, often involving the application of various chemicals during the washing phase. Consequently, denim, in the context of the prevailing climate crisis and its implications for the planet's ecosystems, warrants significant attention as a domain where alternative approaches to conventional methodologies should be devised, with a central focus on eco-friendly methods and innovative technologies, all while preserving the essence of design and originality. In this context, laser technologies are emerging as a prominent solution for advocating environmentally conscious practices without compromising on design and creativity.

Laser, defined as "Amplification of Light through Stimulated Emission of Radiation," operates on the principle of stimulating molecules, atoms, and electrons in an appropriate and active medium. Laser beams are generated through four different methods: solid-state, liquid, gas, and semiconductor, each of which finds application in various industries, including textiles [3]. In the case of CO_2 gas laser systems, the intensity of the laser beam can be adjusted, allowing for pattern creation without creating voids on the surface when reduced [11]. CO_2 gas laser applications in the textile industry are based on the principle of processing the textile surface. These applications, such as laser marking, engraving, cutting, drilling, engraving, welding, and burning, have been used in the textile sector for a long time, serving various functions. Laser marking, among these functions, is an innovative solution that enables the creation of a worn look on denim products without the use of water [12]. It is based on the principle of breaking down and eroding the indigo dye on denim [13]. Considering the amount of water typically used in the dry and wet finishing processes of a denim pair of pants, laser technology emerges as an environmentally friendly approach [3].

Mavi, which began its journey as a local denim brand in Turkey in the early 1990s, has evolved into a globally recognized lifestyle brand today. Positioned as a pioneer among sustainability-focused brands in Turkey, Mavi has demonstrated its commitment to sustainability by receiving sustainability collection awards on a global scale. The All Blue Collection, which reflects the brand's sustainability strategy, continuously evolves with innovative materials, technologies, and approaches each season. The Pro Edition collection, a product of Mavi's efforts to create an entire sustainable denim collection by 2030, is evaluated within the scope of this study [15, 16].

The primary objective of this study is to evaluate the designs of the Mavi Pro Edition collection, which is an enhanced version of the innovative product group that combines denim with the Streetwear and Sporty trends that shape global denim fashion. This evaluation focuses on two key aspects:

1. The Use of Environmentally Friendly Finishing Technology: The study examines the application of laser technology as an environmentally friendly finishing process for the Pro Edition collection. Laser technology, with its minimal environmental impact, is evaluated in the context of sustainable denim production.

2. Adaptation to Changing Consumer Expectations: The study also assesses the collection's potential to meet the evolving consumer expectations, particularly in terms of user comfort. This includes the use of new fiber blends that cater to user comfort preferences and the ability to simultaneously address the needs of different consumer groups.

In summary, this research aims to analyze the Mavi Pro Edition collection from both an environmental sustainability perspective, through the use of laser technology, and a consumer-centric perspective, by considering evolving comfort preferences and diverse consumer needs, within the context of the Streetwear and Sporty trends in global denim fashion.

2. EXPERIMENTAL PART

The primary aim of this study is to examine the products developed by Mavi using laser technology in denim, with a focus on sustainability, durability, and high elasticity principles. The study was designed based on qualitative research methodology. In this regard, a case study approach was adopted to analyze Mavi's products, utilizing data related to fabric, fit research and development, accessory development, design of sewing/cutting details, washing research, product development, evaluation, collection development, and production planning.

A case study involves an in-depth examination and analysis of a particular system or event. Researchers, in the process, seek answers to 'how' and 'why' questions while solving the events. In a case study, data is obtained through observation, visual means, auditory means, and document analysis [17]. Document analysis involves examining written texts, including sources such as web pages, books, videos, newspapers, articles, and reports. It typically involves identifying themes or categories through the examination of written texts and obtaining analysis results through detailed interpretations when analyzing visual data [18].

In the scope of this research, an examination of visual and written sources related to the All Blue collection developed by Mavi's design team was conducted. Data were collected regarding the fabrics, accessories, and washing methods used in the creation process of the Pro Edition product designs within the collection. The details of the data obtained are presented in the results and discussion section.

3. RESULTS AND DISCUSSION

Mavi, in its collections created under the All Blue initiative, has chosen to incorporate high-stretch fabrics, particularly in products where performance and comfort are pivotal. To realize this objective, the company has engaged in partnerships with fabric manufacturers and executed extensive research and development (R&D) endeavors to fashion fabrics integrating an impressive 40% elastane content in the weft threads, resulting in a total elasticity of approximately 20%. These pioneering fabric compositions have been thoughtfully integrated into the design of their products.

The development of these new fabrics, along with advancements in accessories, sewing techniques, and washing details, has allowed Mavi to introduce freshness into their product appearances while prioritizing sustainability and environmentally-friendly designs. Ensuring minimal environmental impact is a fundamental goal of the Mavi brand. Below, an overview of the R&D efforts carried out during the collection process have been presented:

3.1. Fabric and Fit Research and Development

Within the scope of this study, a comprehensive analysis was undertaken to define the fabric prerequisites essential for the designs. Subsequent to this delineation, fabric research was carried out to devise fabrics that seamlessly align with the collection's vision. Furthermore, fit alternatives, which are attuned to the design philosophy as well as customer requisites, were meticulously reevaluated and carefully chosen for incorporation into the Mavi Pro collection.

For the products in this collection, where stretch is a key feature, fabrics with blends of cotton, elastane, and elastomultiester were chosen to ensure both stretchability and resistance to permanent stretching. The cotton content, which provides essential benefits, was kept at around 85% in the fabric blends.

The Pro Edition product group within the collection features slim skinny fits such as Jake and James, which are particularly favored in this segment (Figure 1). What distinguishes these designs are not only the unique color and washing details but also the incorporation of new sewing, cutting, and pleat elements, introduced for the first time by the designers (Figure 2). These designs prioritize achieving a dynamic, active, and youthful aesthetic, which is reflected in the inclusion of more stitching details than typically used in denim garments.

Figure 1. Mavi Gold Shape Jean/ Slim Skinny Fit

Figure 2. Mavi Jean/ Washing and Stitching Details

3.2. Accessory Development and Sewing/Cutting Detail Design

This section of the study encompasses the creation of a metal plate tailored to the Mavi Pro logo and the development of various cutting, pleating, stitching intervals, and punteriz details designed to achieve a unique look distinct from the classic appearance of five-pocket denim pants (Figure 3).

Figure 3. Mavi Premium Jean/Punteriz Stitching Details

3.3. Washing Research

The washing research conducted for this collection encompasses the development of surface effects desired for the products. This research takes into consideration both laser technologies and the traditional washing processes that are currently in use. Furthermore, it focuses on enhancing the diversity of visual effects in various fabric colors.

To capture the prevailing vintage trend, extensive work has been carried out with fabrics of different color tones suitable for generating distinctive effects during the washing process (Figure 4). The desired effect was successfully achieved by producing items with a hazy green nuance on indigo, termed as "lime blue." This distinctive touch allowed the products to stand out from the conventional indigo denim.

While adhering to the existing washing process, the incorporation of laser technology for creating whiskering effects resulted in more pronounced outcomes in terms of color and appearance. This not only enhanced the visual appeal but also contributed to sustainability. Additionally, a novel metal accessory design was developed for the front pocket of denim pants, introducing a form that is featured for the first time in this collection.

Figure 4. Vintage Street Jean/Washing and Pocket Design

The utilization of laser technology in finishing processes has not only facilitated the achievement of the desired surface effects but has also opened up various design possibilities. This approach significantly contributes to environmental sustainability by reducing water and energy consumption during the washing process.

The Pro Edition collection by Mavi not only introduces products with more daring design features for the existing users of the Mavi Pro collection but also effectively reaches its goal of appealing to a younger audience, particularly within the 18-25 age group. As part of the All Blue initiative, a comprehensive 14-piece collection has been developed, encompassing 4 denim pants and 10 products for the Pro Edition and Pro product groups in the corresponding season.

4. CONCLUSIONS

The Pro Edition collection was created within the Mavi Pro SS23 collection. With the Pro Edition package, a product group with a bold design character was introduced within the Mavi Pro collection. This collection, tailored for individuals who embrace a productive, creative, and collective lifestyle, successfully engaged both the existing Mavi Pro collection users and new customers aged 18-25, effectively appealing to both Generation Y and Generation Z.

For the Pro Edition package, four denim pants were designed, each differentiated by washes, details, and color features in slim skinny and skinny fits. The pants feature new metal logo/plate designs specific to the Pro Edition package, with a focus on integrating the designed metal plates seamlessly with the products. The chosen fabrics for the designs have demonstrated their ability to maintain the shape of the products with elasticity tests ranging from a minimum of 3% to a maximum of 6% stretching.

The brand's commitment to sustainability is evident through the inclusion of laser technology in finishing processes in the Pro Edition collection. This not only led to reductions in water and energy usage but also made significant contributions to the well-being of workers and the environment by mitigating the formation of indigo dye particles and cotton fiber lint.

The Pro Edition collection, driven by the brand's positive response to the interest and enthusiasm shown by users of the Mavi Pro collection, has introduced new and innovative features in terms of details, fabric content, and washing to its existing product range.

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RESEARCH ON THE CREATION OF SPATIAL FORMS USING THE MOLDING TECHNIQUE

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***Abstract**. To obtain the spatial shape, the direction of the textile fibers is changed by moisture-thermal treatment or using the molding technique. The paper presents the process of creating spatial forms using the molding technique. The main purpose is to present how to use various software, machines and equipment used in the process of developing three-dimensional matrices. The stages of creating volumetric shapes in clothing products are also presented. The work presents the results of a theoretical and practical study, carried out within the studies at the Academy of Textiles and Technologies in Barcelona "Fabricademy". The use of CAD/CAM systems and manual techniques in the creation of clothing can bring many benefits such as: creativity and expression, efficiency and productivity, accuracy and consistency, reduction of errors and waste, flexibility and adaptability, improved collaboration, design in detail, easy reproduction, virtual design exploration, integration of technology and innovation. The use of manual techniques and CAD/CAM systems in the creation of clothing represents an integration of technology and innovation in the field of fashion, allowing designers to adapt to new trends and express their ideas in an advanced and effective way. These results can be used to diversify the range of clothing products using CAD/CAM systems.*

***Keywords:** Wood molds, CAD/CAM systems, complex surface, hard wood.*

1. INTRODUCTION

The molding technique is used in the creation of complex spatial forms by renowned fashion houses around the world in the process of creating haute couture clothing products. Haute couture clothing impresses with the boundless imagination of the designer. It sets trends that are quoted from season to season. Stunningly beautiful outfits are chosen by celebrities to appear at various important events such as Oscars, Golden Globes, Cannes Film Festival, etc [1]. Beginning in the mid-nineteenth century, Parisian haute couture fashion created an unique system that validated the tailor as an artist and established his "renown" as an international authority on high-class clothing design.

Women's haute couture clothing is a true work of art, with each outfit created almost entirely using handwork or ancient tailoring techniques. Most haute couture items exist in only one copy. It takes 100 to 400 hours to make an outfit. In exclusive clothing manufacturing, approximately 70% of production is done by hand. One of the methods of creating haute couture dresses, widely used by designers, is the technique of obtaining spatial shapes using various types of molds.

The paper presents the process of creating spatial forms using the molding technique. The main purpose is to present how to use various software, machines and equipment used in the process of developing three-dimensional matrices. The stages of creating volumetric shapes in clothing products are also presented. The work presents the results of a theoretical and practical study, carried out within the studies at the Academy of Textiles and Technologies in Barcelona "Fabricademy".

2. THEORETICAL PART

2.1. Examples of applications

The technique of creating haute couture dresses using different molds is a very old but effective one that allows obtaining a correct copy. It is widely used in the creation of clothing products or decorative elements included in the wearer's costume (figure 1) [3]. We also observe the same trend in the creation of accessories such as: bracelets, earrings, belts, bags, travel luggages, etc. (figure 2) [4, 5].

Figure 1. Clothing products made using the molding technique

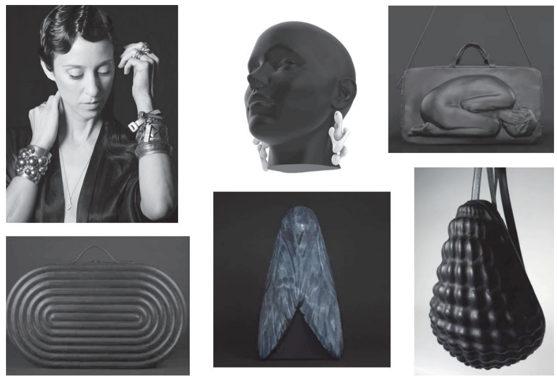

Figure 2. Accessories made using the molding technique

2.2. Methods of obtaining volumetric shapes using the moulding technique

If we analyse the methods of obtaining spatial forms with the help of molds, we notice that there are two methods, which can be used depending on the skills of the designer (figure 3).

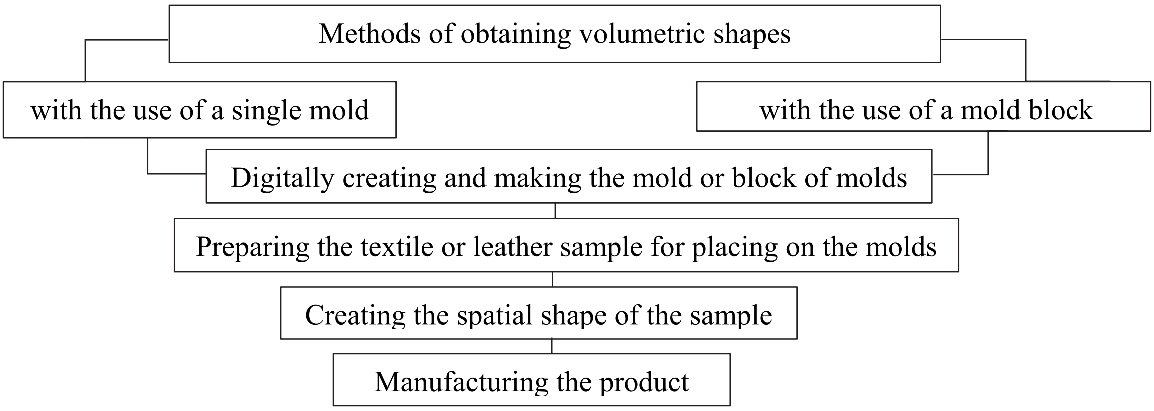

Figure 3. Methods of obtaining volumetric shapes

The first method of creating volumetric shapes uses a single volumetric mold on which all constructive lines, decorative folds, ornamental elements, etc. are engraved [3]. These are the stages:

- The digital creation and actual fabrication of the volumetric mold (figure 4, 5) – the mold is created using standardized mannequins, which are then adapted to the wearer's body and the product outline; the outer layer is sanded and covered with a protective layer.
- The preparation of the textile or leather sample for placing it on the molds (figure 6) – natural materials go through the process of preparation with special substances; natural leather is soaked in hot water for 30 minutes.
- The creation of the spatial shape of the sample (figure 7) – placing the sample on the mold, arranging it and clamping the edges.
- The manufacturing of the product (figure 8) – assembling the parts of the product according to the sketch.

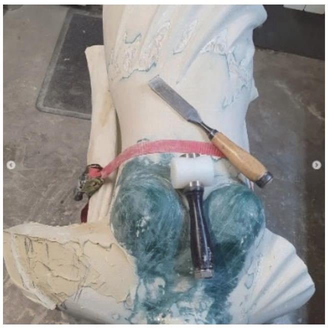

Figure 4. Adaptation of the mold to the body of the wearer and to the outline of the product

Figure 5. The mold in the final stage of processing

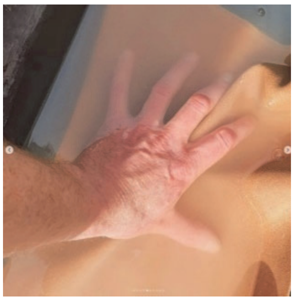

Figure 6. Natural leather preparation

Figure 7. The step of arranging the sample on the mold

Figure 8. Final presentation of the product

The same matrix can be used to make clothing products from natural materials of various types (figure 9).

Figure 9. Collection created by Robert Mercier, 2022 [3].

The second method of creating volumetric shapes uses a block for 3D mold with a positive and negative design on the inside [6, 7]:

- The digital creation and making process of the mold block (figure 10) – digital molds are created using various three-dimensional software and manufactured using the milling machine.
- The sample preparation (figure 11) – the materials are prepared in the same way as in the previously presented method, then they are manually arranged in the mold.
- The creation of the spatial shape of the sample (figure 12) – to obtain the imprint of the matrix block, it is necessary to press it using various weights or clamps.
- The extraction of the sample and manufacture of the product (figure 13) – the sample is extracted and, if necessary, goes through a finishing process to maintain the rigid shape during the exploitation process.

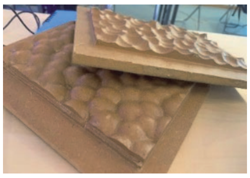

Figure 10. Mold blocks created from wood

Figure 11. Sample preparation

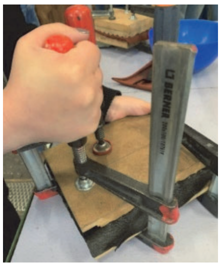

Figure 12. Placing the sample on the mold block

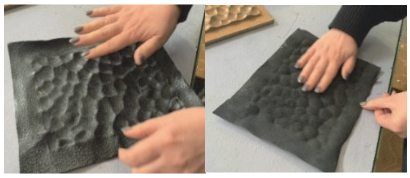

Figure 13. Sample extraction

Both methods presented were exemplified by natural leather samples, but other types of natural materials can also be used.

3. EXPERIMENTAL PART

The results presented below were obtained during the studies carried out at the Academy of Textiles and Technologies in Barcelona "Fabricademy" [6, 7]. Two molds models with different designs were created.

3.1. The creation and analysis of the sketch

This stage is seen as a creative process where the designer experiments with shapes, structures and textures. Also, at this stage, the model is analysed and the way of creating the spatial shape of the product, the type of material used, the way of making the model is specified. For this stage, the design of patterns and virtual 3D prototype was developed using the CLO3D prototyping software [8]. The use of various types of natural materials was planned (figure 14).

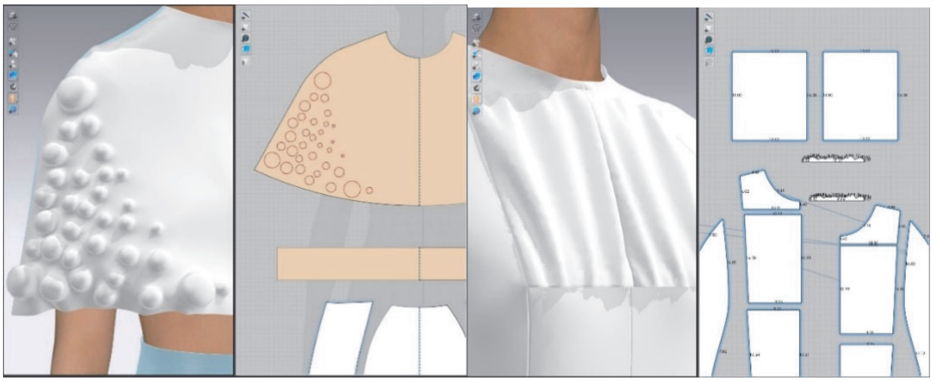

Figure 14. The design of patterns and virtual 3D prototype in CLO3D

3.2. The digital creation of the mold block

This stage is a stage that requires knowledge in the use of three-dimensional design software. Rhino software [9] was used to create the digital molds. Rhino software is a tool used in three-dimensional design and can be used in the process of creating complex volumetric shapes in the design of clothing products. Initially, the digital form of the matrix block was developed. The following steps were taken:

- Creating the initial shape with the size of 20cm x 20cm x 2cm (figure 15);
- Developing the algorithm for modifying the mold block design (figure 16);
- Creating the mold block design (figure 17);

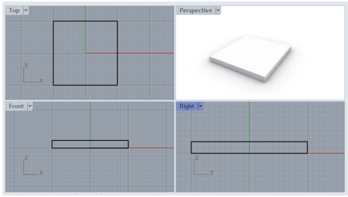

Figure 15. Mold blocks created from wood

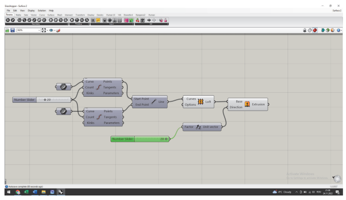

Figure 16. Algorithm made in Rhino's application module called Grasshopper

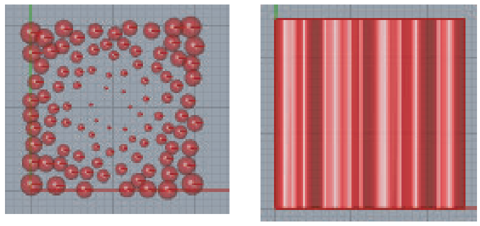

Figure 17. The solid shape of the mold block design

- Creating the block of molds by gluing and excluding the decoration from the block of molds (figure 18);

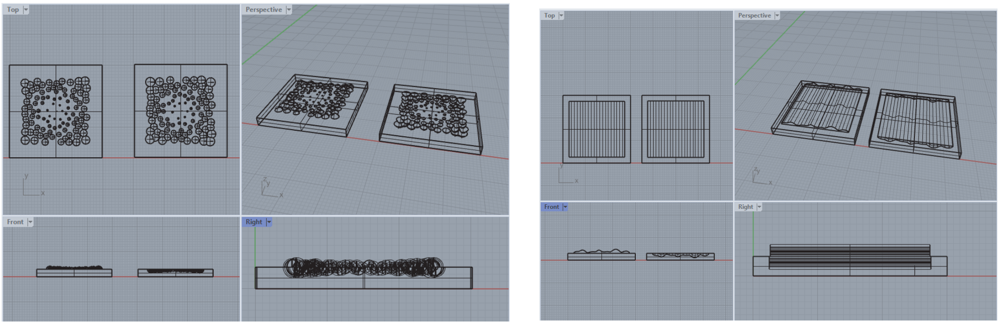

Figure 18. Using the "paste" and "exclude" tools

- Exporting the mold block in stl format, necessary for the use of the milling machine (figure 19);

Figure 19. The final mold block shape

3.3. The making process of the mold block

The mold block was made of oak wood, which is durable and has an attractive texture. This stage was carried out with the help of colleagues from FabLab Chisinau [10]. Initially, in the wood was processed using the Helical JET 15HH Powermatic 1791213-RU-M belt planer (figure 20). That machine allowed obtaining the initial rectangular shapes of the mold block (figure 21). The next stage was carried out on the GM-2036 ATC milling machine (figure 22).

Figure 20. Belt planer machine Helical JET 15HH Powermatic 1791213-RU-M

Figure 21. Initial mold block shape

Figure 22. Milling machine GM-2036 ATC

Initially, the wooden boards must be fixed on the table of the machine. The machine was turned on. The x and y axis was set in the corner of the wooden board and the z axis slowly moves the bottom tool until it touches the board. The next action involves loading the milling code, turning on the air exhaustion and pressing the print button. In the end, two matrix blocks were obtained (figure 23)

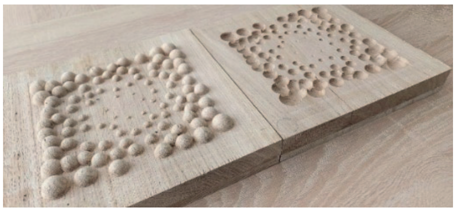

Figure 23. Wooden block for 3D molds

3.4. The creation of the spatial shape of the sample using the wooden block for 3D mold

Two types of natural materials were used for this stage: linen, felt and paper made from tea bags and leaves.

Initially, the process of preparing the materials was carried out. Then, they were placed between the mold blocks and left until completely dry. The obtained results are shown in figure 24, 25 and 26.

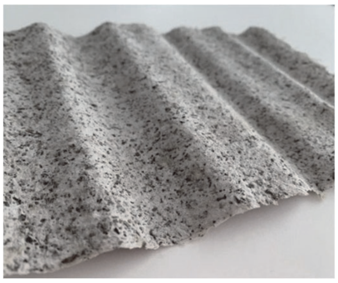

Figure 24. Volumetric form of paper made from tea bags and leaves

Figure 25. Volumetric form made of linen textile

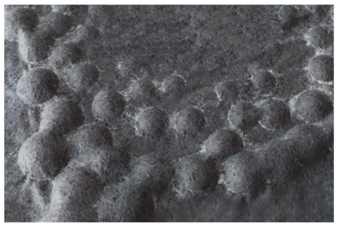

Figure 26. Volumetric form made of felt

4. CONCLUSIONS

Manual techniques for obtaining spatial forms in clothing give designers the opportunity to create unique and innovative structures and silhouettes. Designers can shape textiles by hand to achieve three-dimensional shapes, adding volume and texture to garments and paying close attention to details.

Manual techniques for obtaining spatial forms have a number of advantages. Here we can experiment with different materials. This allows for experimenting with textures, consistencies and unique properties of each material, learning how to use them creatively. Also, these techniques can be used to give life to recycled or reused materials. You can turn old objects or scraps into works of art or functional objects, thus helping to reduce waste and promote sustainability.

When manual work intersects with CAD/CAM systems, many other advantages appear that allow the creative diversification of the assortment of clothing products.

The use of CAD/CAM systems and manual techniques in the creation of clothing can bring many benefits such as:

Creativity and expression: Both manual techniques and CAD/CAM systems allow designers to express their creativity and create unique and innovative clothing designs.

Efficiency and productivity: CAD/CAM systems allow designers to create patterns and adjust them quickly and efficiently, saving time and effort in the garment creation process.

Accuracy and consistency: The use of CAD/CAM systems allows accurate and uniform designs to be achieved, ensuring consistency in mass production of clothing.

Reduction of errors and waste: CAD/CAM systems can reduce human error and thereby the risk of having defective products, helping to reduce waste and make the production process more efficient.

Flexibility and Adaptability: Manual techniques allow designers to adjust designs in real time and experiment with different materials and techniques, providing flexibility and adaptability in the creative process.

Improved collaboration: CAD/CAM systems facilitate collaboration between designers, tailors and manufacturers, enabling the sharing and rapid modification of designs to ensure effective communication throughout the production chain.

Design in detail: CAD/CAM systems offer the ability to create complex models in detail, with precision and accuracy, without the need to manually repeat certain elements.

Easy reproduction: The use of CAD/CAM systems allows fast and accurate reproduction of designs, which is beneficial for mass production of clothing.

Virtual design exploration: CAD/CAM systems offer the ability to view and test models in the virtual environment before their physical production, saving time and materials.

Integration of technology and innovation: The use of manual techniques and CAD/CAM systems in the creation of clothing represents an integration of technology and innovation in the field of fashion, allowing designers to adapt to new trends and express their ideas in an advanced and effective way.

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EFFECT OF VOLTAGE ON PAN-BASED CARBON NANOFIBERS PROPERTIES DURING ELECTROSPINNING

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Abstract. *The aim of the study is to investigate the effect of the electrospinning applied voltage on the carbon nanofiber properties. In this study, polyacrylonitrile (PAN) was selected as a precursor polymer for the carbon nanofiber preparation. A proper homogenous solution was prepared by dissolving PAN in N,N-Dimethylformamide (DMF) and electrospun into nanofibers under different voltage values (10, 15, 20 and 25 kV). These nanofibers were subsequently transformed into carbon nanofibers (CNFs) through stabilization in air and carbonization in nitrogen atmospheres involving high-temperature treatments. The morphology of both PAN nanofibers produced under different voltages and their analog carbon nanofibers were analyzed using scanning electron microscopy (SEM). The thermal properties of PAN nanofibers were investigated through differential scanning calorimetry (DSC) analysis. Structural changes in carbon nanofibers were examined using Raman spectra analysis method. High-temperature processes such as stabilization and carbonization reduced the diameters of the nanofibers. Among the effects of increasing voltage, the carbon nanofibers produced at 20 kV exhibited the lowest nanofiber diameter and also had the lowest Full Width at Half Maximum (FWHM) value in Raman analysis. A relationship was investigated between the DSC analysis results of as-spun PAN nanofibers and the Raman analysis results carbonized nanofibers.*

Keywords: *Carbon nanofibers, electrospinning, stabilization, carbonization, electrospinning parameter*

1. INTRODUCTION

Carbon nanofibers, along with other one-dimensional (1D) nanostructures like nanowires, nanotubes, and graphene, have garnered significant attention due to their high length-to-diameter ratios. This property enables the production of advanced materials by using them in potential applications such as nanocomposites [1], nanotubes [2], filters [3], re-chargeable batteries[4] and supercapacitors [5]. Electrospinning is one of the primary techniques used in the production of nanofibers. There are numerous studies that investigate the effects of different electrospinning parameters on nanofiber morphology. [6], [7].The electrospinning process is a technique that utilizes electrostatic forces to create polymer jets, which are used to produce nanofibers. The high potential difference used in this process generates significant electrostatic forces that impact the polymer. [8]–[10]. Due to the difficulty in controlling the parameters involved in the electrospinning process, the investigation of molecular orientation has been primarily conducted by using rotating collectors. [11], [12].

Polyacrylonitrile (PAN) polymer is one of the precursor polymers used in the production of carbon nanofibers (CNF). It needs to undergo stabilization and carbonization processes for this transformation. [13], [14]. In addition to the electrostatic forces applied during the electrospinning process, various stresses also arise during the applied stabilization process, which can influence molecular orientation. [14].

This study aims to elucidate the relationship between the applied voltage and its impact on nanofiber morphology, molecular orientation and finally carbon nanofiber properties. Scanning Electron Microscopy (SEM) was employed to identify morphological changes of the nanofibers, raman spectroscopy to detect molecular orientation, and differential scanning calorimetry (DSC) to determine thermal properties and crystalline structure.

2. METHODOLOGY

2.1. Materials and Methods

Preparation of the Solution

A PAN with a molecular weight of 150,000 was purchased from Sigma Aldrich. N,N-Dimethylformamide (DMF) was used as the solvent. An 8wt.% PAN/DMF solution was prepared by stirring at 50 rpm for 2 hours at room temperature using a magnetic stirrer.

Electrospinning Process

The prepared solution was put into a 10 ml sterile syringe and subjected to the electrospinning process by using a 21G needle. Nanofiber deposition onto a stationary plate was carried out with a linear feed pump at a feeding rate of 1 ml/hr. The distance between the needle and the stationary plate was 10 cm, and nanofiber production was sustained for 5 hours.

Four experimental groups were prepared, with applied potential differences of 10, 15, 20, and 25 kV, respectively. In these experimental groups, PAN was used as the precursor, and stabilization and carbonization processes were performed to obtain carbon nanofibers.

Stabilization Process

The PAN nanofibers were subjected to a stabilization process in an atmosphere at Protherm Furnaces high-temperature furnace (280°C for 60 minutes) with a heating rate of 10°C/min.

Carbonization Process

Following stabilization, the nanofibers were subjected to a carbonization process in a nitrogen gas atmosphere using a Protherm Furnaces high-temperature furnace (800°C for 120 minutes) with a heating rate of 10°C/min. (Nitrogen gas flow rate: 1 L/min).

2.2. Characterization

For the morphological characterization of these experimental groups, a ZEISS GeminiSEM 300 model scanning electron microscope (SEM) was used. Before measurement, all samples were coated with a 10 nm thick layer of Au/Pd. Nanofiber diameters were measured using Image J software. To determine carbon nanofiber properties, Raman spectroscopy analysis was conducted using a Renishaw inVia instrument with a 532 nm laser beam. To determine the thermal capacity and the crystallinity ratio values of the as-spun nanofiber samples, a TA Instruments DSC250 model Differential Scanning Calorimeter (DSC) device was used. The test range was from -80°C to 400°C with a heating rate of 10°C/min.

3. RESULTS AND DISCUSSION

3.1 Discussion of SEM Results of PAN Nanofibers

After the production of PAN nanofiber surfaces through electrospinning and subsequent stabilization/carbonization processes, SEM imaging was performed and demonstrated in Figure 1. This allowed the observation of the effects of stabilization/carbonization processes on nanofiber morphology.

The average diameter values of the nanofibers are given in Table 1. Average dimeter was increased with the increasing in applied voltage up to 20 kV. However, at 25 kV, there was a decrease in the average nanofiber diameter. As seen from the SEM images in Figure 1, magnified images reveal that the nanofiber surfaces are rough. In sum, except the average nanofiber diameter change, no big morphological differences were observed.

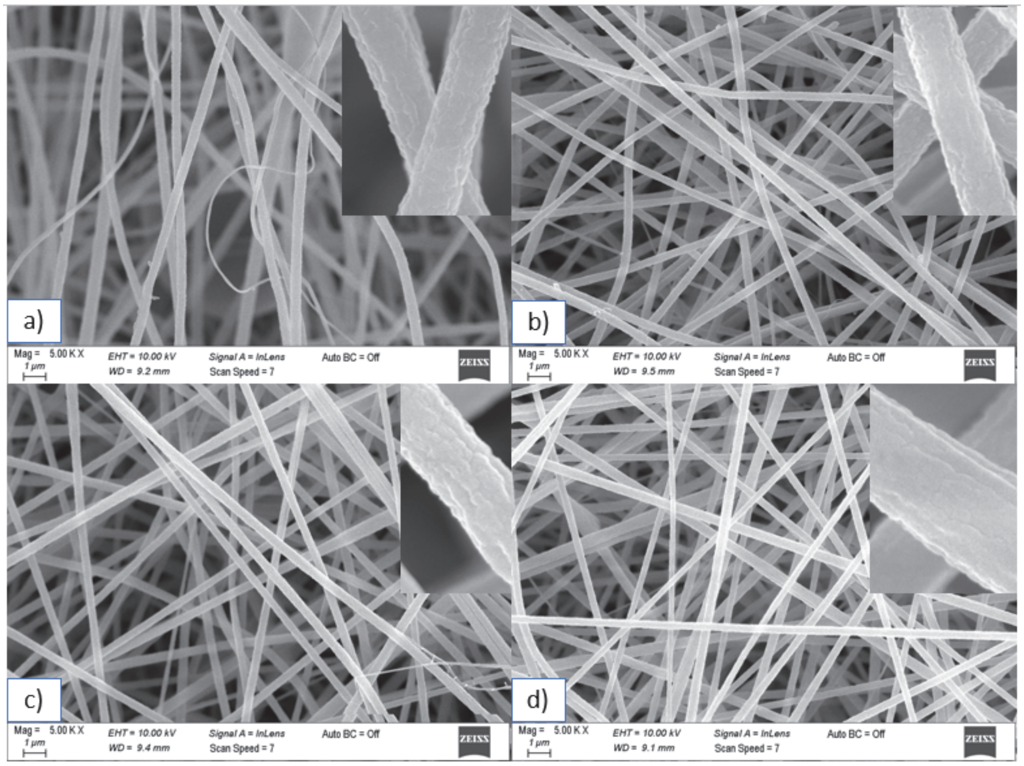

Figure 1. %8 PAN nanofibers according to applied voltage a) 10 kV, b) 15 kV, c) 20 kV, d) 25 kV

Table 1
%8 PAN nanofibers in sequence 10, 15, 20, 25 kV

Experimental Group	**Contents of the Experimental Group**	**Average Nanofiber Diameters (nm)**
A	%8 PAN/DMF nanofiber - 10 kV	352
B	%8 PAN/DMF nanofiber - 15 kV	360
C	%8 PAN/DMF nanofiber - 20 kV	368
D	%8 PAN/DMF nanofiber - 25 kV	289

3.2. Discussion of DSC Results of PAN Nanofibers

DSC was used to measure and analyze the response of polymers to heat. It characterizes polymer materials by properties such as heat capacity, glass transition temperature, crystallization temperature, and melting temperature. The use of DSC in polymer studies helps to determine the transition enthalpy, degree of crystallinity, and thermal conductivity of polymer materials [15].

DSC analysis was recorded with a heating rate of 10 °C/min from -80 °C to 400 °C. Various parameters obtained from the DSC curves were summarized, including the initial temperature (T_i), final temperature (T_f), the temperature difference between them ($\Delta T = T_f - T_i$), maximum temperature (T_m), enthalpy (ΔH), and the ratio of enthalpy change ($\Delta H/\Delta T$)[16] .

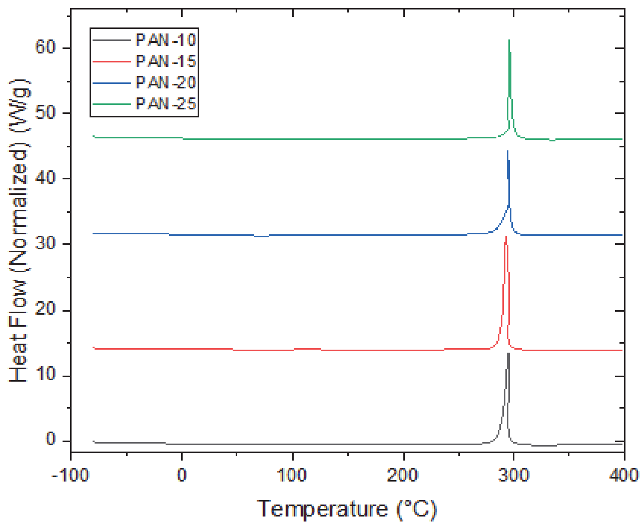

Figure 2. DSC plots of as-spun PAN nanofibers.

As seen in Figure 4, there is no endothermic peak indicating melting on the curves; only exothermic peaks have been observed[17]. As seen in Table 4, the enthalpy value for PAN-10, which is 458.62 J g^{-1}, decreased to 442.71 J g^{-1} in the PAN-20 experimental group. It was observed that as the applied potential difference during electrospinning increased, the crystallization onset and maximum temperatures of the experimental groups shifted to higher temperatures.

Table 2.
Results of DSC analysis

Samples	T_i (°C)	T_m (°C)	ΔH (J g^{-1})
PAN-10	288.68	295.13	458.62
PAN-15	288.10	295.59	455.79
PAN-20	291.27	296.88	442.71
PAN-25	293.59	299.01	454.34

One possible reason for the expansion of the exothermic peak is the formation of nanofibers with a regular structure. In the literature, it has been observed that as the surface area increases and the diameter decreases, there is an increase in enthalpy values [18]. The highest nanofiber diameter and the lowest enthalpy value were found in the PAN-20 experimental group. Furthermore, the contraction of the exothermic peak also indicates that the polymer has a poorer crystalline structure. This suggests that the polymer has a low degree of molecular order and exhibits a more irregular or amorphous structure. Such a structure reflects a situation where polymer chains are randomly distributed or packed in an irregular manner. Consequently, the PAN-20 experimental group, having the lowest ΔH value, represents the group with the poorest crystalline structure [18]–[20].

3.3. Discussion of SEM Results of Carbon Nanofibers

After the stabilization and carbonization processes, the nanofiber diameters decreased in all experimental groups. During carbonization, various gases (such as H_2O, N_2, HCN and others) are evolved, and the carbon content increases up to ~90 wt.% or higher. Therefore, the process leads to the formation of three-dimensional carbonaceous structures and a decrease in nanofiber diameter [21].

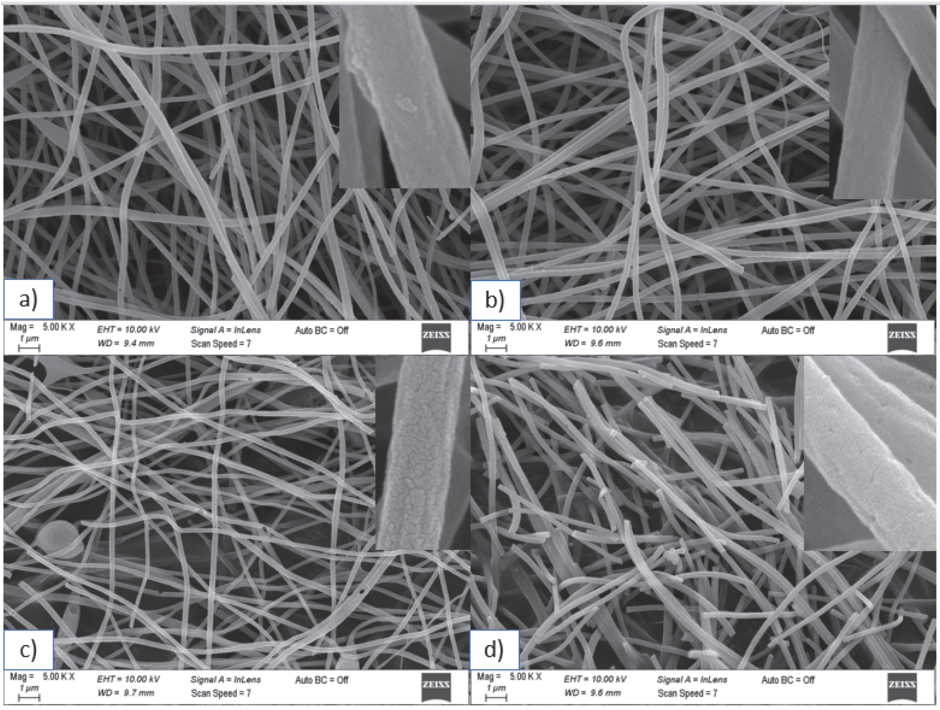

Figure 3. CNF according to applied voltage a) 10 kV, b) 15 kV, c) 20 kV, d) 25 kV

The magnified images in Figure 3 reveal that the carbon nanofiber surfaces are smoother compering their as-spun PAN nanofiber analogs. Fiber breakage after carbonization is more significant at 25 kV spun sample (Figure 3c).

Table 3.
CNF in sequence 10, 15, 20, 25 kV samples.

Experimental Group	Contents of the Experimental Group	Average Nanofiber Diameters (nm)
A	%8 PAN/DMF nanofiber --> CNF-10 kV	351
B	%8 PAN/DMF nanofiber --> CNF-15 kV	310
C	%8 PAN/DMF nanofiber --> CNF-20 kV	213
D	%8 PAN/DMF nanofiber --> CNF-25 kV	260

3.4. Discussion of Raman Results of Carbon Nanofibers

Raman spectroscopy is a tool used for the characterization and studying the phases and phase transitions of various nanostructured materials. It is employed to identify amorphous or crystalline regions, defect distributions, and the shape and size of nanomaterials[22].

The G band arises as a result of the planar arrangement of sp^2 hybridized carbon atoms, and this regularity indicates that the carbon material's structure is as regular as graphene[23], [24]. After carbonization, D and G bands were observed in all experimental groups. This indicates the success of the carbonization process[23], [24]. The full width at half maximum (FWHM) of the Raman spectrum is an indicator of the crystalline quality[25]. A decrease in this value in Raman analysis indicates a reduction in defects in the material [26]. In the raman results, as shown in Figure 4 and Table 4, the FWHM value of the G band was observed to be the lowest in C-CNF (carbonized of 20kV as-spun PAN NFs). This indicates a more homogeneous and crystalline structure and suggests that this sample has the best molecular orientation, with the most prominent G band peak occurring in this sample.

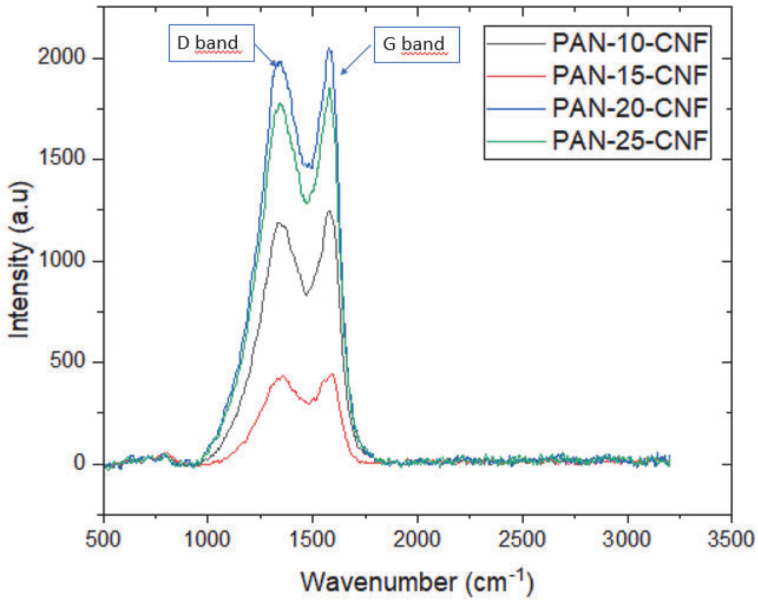

Figure 4. Raman Results of Carbon Nanofibers

Table 4.
Raman analysis results

Sample Type	D band peak			G band peak			I_D / I_G ratio	Average Nanofiber diameters (nm)
	Wave number (cm^{-1})	Intensity (a.u.)	FWHM (cm^{-1})	Wave number (cm^{-1})	Intensity (a.u.)	FWHM (cm^{-1})		
A-CNF	1338	1191	246.441	1580	1252	169.198	0.95	351
B-CNF	1360	436	248.687	1595	440	157.330	0.99	310
C-CNF	1341	1987	272.629	1576	2048	140.747	0.97	213
D-CNF	1346	1778	255.122	1580	1852	164.631	0.96	260

4. CONCLUSION

Before carbonization, there was no proportional relationship observed between the applied voltage and the changes in nanofiber diameter as the voltage increased. The average highest nanofiber diameter before carbonization and the lowest enthalpy value in the DSC analysis belong to the PAN-20 experimental group. Therefore, it can be said that the experimental group with the lowest crystalline structure is the PAN-20 experimental group. Following carbonization, the smallest nanofiber diameter was associated with nanofibers produced at 20 kV during electrospinning. This experimental group exhibited the highest intensity of D and G band peaks in the Raman results. This indicates that the stabilization and carbonization processes play a significant role in the crystalline structure. It is noteworthy that the experimental group, initially identified as having the lowest crystalline structure by DSC, demonstrated the potential to achieve the best crystalline structure of the carbon nanofibers through thermal processes.

Acknowledgement

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ONE-PIECE WEAVING OF A DOUBLE-WALLED TUBULAR 3D-FABRIC WITH TWO CONNECTING ELEMENTS

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Abstract. *3D-woven fabrics are used as reinforcement in composite materials for numerous applications in fields such as industrial, aeronautical, medical or sports. The paper presents the design and manufacturing process of a double-walled tubular 3D-woven fabric. The two coaxial tubes are connected to each other by two diametrically opposed elements, which divide the annular area into two spaces of equal size and help to maintain the distance between the tubes. All the elements are linked, being made by a single weaving operation, in a flattened state of the tubular elements. The design process has as initial data the inner diameters of the two tubes and establishes the steps of calculation algorithm to determine the main parameters of the 3D-multilayer woven structure (width and number of warp yarns for each cross-sectional area of weave design). Different variants of weft yarns insertion order are explored, with the presentation of advantages and disadvantages of each. Woven samples made on an ARM Selectron Patronic shuttle loom equipped with 18 shafts, using polyester and cotton yarns, demonstrated the validity of the proposed design process. Using yarns and densities suitable for certain destination, the proposed 3D structure can be used for industrial filters (for liquid/solid/air filtration), heat-insulating pipes (if the annular space is filled with insulating materials – foam, fibres, etc.), or as reinforcement for composite materials (e.g., double wall piping systems from glass fibre reinforced plastic). Future research will include the weaving of the proposed 3D-structure with glass yarns, making and testing of glass fibre reinforced composite with double-walled structure.*

Keywords: *engineered fabrics, 3D-woven structures, double-walled woven tube, technical textiles, tubular reinforcement for textile composites.*

1. INTRODUCTION

The increasing use of textile materials in various technical fields is determined by several of their common characteristics, such as light weight, flexibility, durability and cost-effectiveness. Another key reason is the wide range of textile structures that can be designed and produced to meet the specific demands of the intended application. 3D-woven fabrics are used as reinforcement in composite materials for numerous applications in fields such as industrial, aeronautical, medical or sports [1, 2, 3].

Two-ply woven fabrics are 3D structures which contain at least two warp systems and two weft systems of yarns, which will constitute two simple layers [4]. If the two layers are only connected at the two edges of the woven fabric, a tubular fabric is obtained. When woven on a shuttle loom with the weft yarn looping circumferentially from the bottom layer to the top layer, then a tube with strength can be achieved [5]. Applications for tubular woven fabric include fire hose, vascular grafts, seamless closed loop belting products, air inflated beams and ducting, high temperature filter bags, and composite piping and tubes [5]. In the literature, there are some studies related to the design and manufacturing of 3D tubular woven structures for various purposes [6, 7, 8], but there are no mentions on 3D double-walled tubular structures.

The paper presents the design and manufacturing process of a double-walled tubular 3D-woven fabric produced in one step, using a conventional weaving machine. The two coaxial tubes are connected to each other by two diametrically opposed elements, which divide the annular area into two spaces of equal size and help to maintain the distance between tubes. All the elements are linked, being made by a single weaving operation, in a flattened state of the tubular elements.

Using yarns and densities suitable for certain destination, the proposed 3D structure can be used for industrial filters (for liquid/solid/air filtration), heat-insulating pipes (if the annular space is filled with insulating materials – foam, fibres etc.), or as reinforcement for composite materials (e.g., double wall piping systems from glass fibre reinforced plastic).

One-piece manufacturing can offer advantages such as reducing subsequent manufacturing operations for tubular filters or increasing mechanical strength through the presence of continuous yarn in the reinforcement in the case of fibre-reinforced composites.

2. THE DESIGN PROCESS

In order to weave the tubular 3D structure on a classic weaving machine as a multilayer fabric, it must first be flattened. The flattening can be done so that the obtained multilayer structure is either symmetrical or asymmetrical with respect to a vertical axis. Figure 1 illustrates the cross-section of the 3D-woven fabric in open state (Fig. 1-a) and the two flattening variants: symmetrical (Fig. 1-b) and asymmetrical (Fig. 1-c). In open state, two coaxial tubes of the same thickness *t,* with inner radii *R* and *r* respectively, are connected to each other by two diametrically opposed elements which divide the annular area of width *a* into two spaces of equal size (Fig. 1-a). In flattened state, the component areas of the 3D-multilayer woven structure are identified and denoted A, B, C, D and E for the symmetrical variant (Fig. 1-b) and B′, C′, D′ and E′ for the asymmetrical variant (Fig. 1-c).

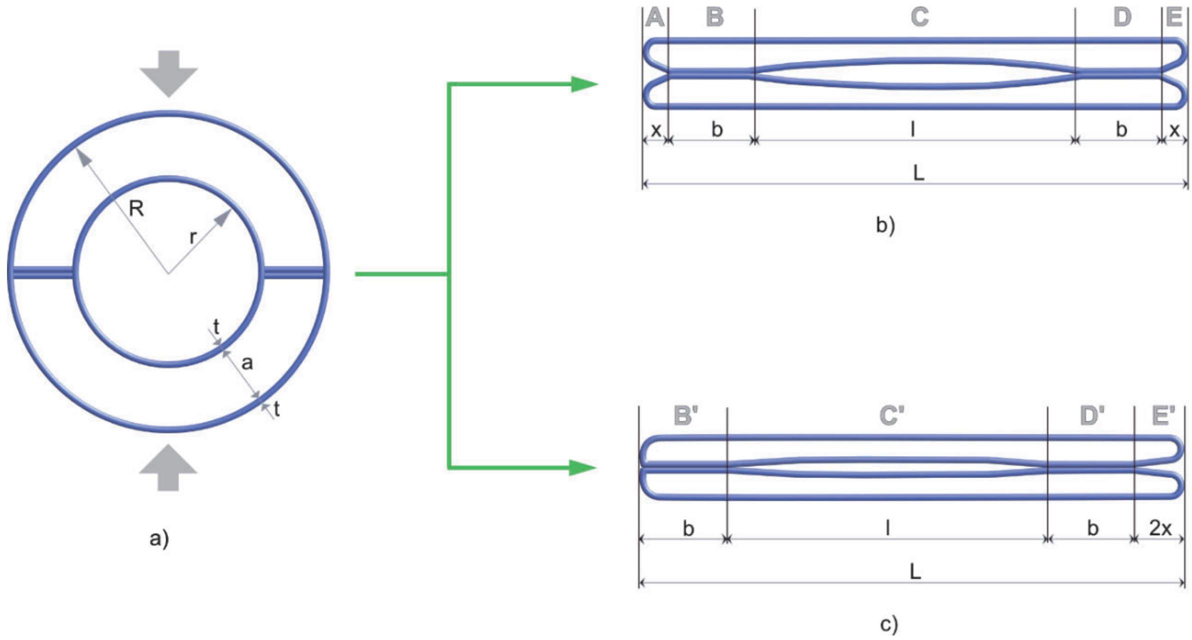

Figure 1. Cross-sections of the 3D-woven fabric

a) open state; b) symmetrical flattened state; c) asymmetrical flattened state

The design process has as initial data the inner diameters (radii) of the two tubes (*R, r)* and the thickness of tube walls (*t*) and aims to establish the calculation algorithm to determine, in the first step, the widths of each different section formed after flattening the tubes. In the second step, the required number of warp yarns is determined to ensure obtaining the calculated width of each area. Finally, the order of weft insertion that allows weaving the multilayer tubular structure is established.

2.1. Calculation of width of each cross-sectional area of multilayer woven fabric

For both flattening variants, these widths were noted as follows (Fig. 1-b, c):

l - the width of areas C and C′
b - the width of areas B, D, B′ and D′
x - the width of areas A and E (due to the asymmetrical flattening, the width of area E′ is equal to *2x*).

When the 3D structure is flattened, *x* represents the overlaps created by folding the outer tube, areas *b* are the connecting elements and areas *l* result from the flattening of the inner tube. The fabric width *L* is calculated as the cumulative sum of these areas (Fig. 1-b and Fig. 1-c):

$$L = 2x + 2b + l \quad (1)$$

Figure 2 details the area where the connecting element on the left side is attached to the two tubes, in the two flattening variants – symmetrical (Fig. 2-a) and asymmetrical (Fig. 2-b). According to Fig. 2, the width of component areas b is given by the relationship:

$$b = a + 2t \quad (2)$$

where a is the width of the annular area between the interior surface of the outer tube and the exterior surface of the inner tube and t represents the thickness of the tubes (Fig. 1-a).

$$a = R - (r + t) \quad (3)$$

After replacing of a in equation (2), the following expression for b is obtained:

$$b = R - r + t \quad (4)$$

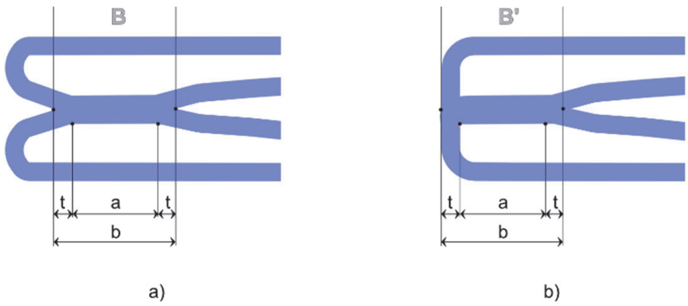

Figure 2. The left side of the tubes in flattened state
a) symmetrical flattening; b) asymmetrical flattening

The width of l area is equal to width of flattened inner tube:

$$l = \pi r \quad (5)$$

As stated before, the fabric width L is given by the equation (1). This width can also be expressed as:

$$L = \pi(R + t) - 2x \quad (6)$$

By equating relations (1) and (6) and substituting the expressions for b and l, it can be written:

$$\pi(R + t) - 2x = 2x + 2(R - r + t) + \pi r$$

from where:

$$4x = \pi(R + t) - 2(R - r + t) - \pi r$$

$$4x = \pi(R - r) - 2(R - r) + t(\pi - 2)$$

After performing the necessary calculations and grouping the terms in a convenient manner, it is obtained:

$$x = \frac{(\pi - 2)}{4}(R - r + t) \quad (7)$$

$$x = 0.2854 \cdot (R - r + t) \quad (8)$$

By replacing the expression (4), (5) and (7) in equation (1), the fabric width L can be calculated with the following relation:

$$L = \left(\frac{\pi}{2} + 1\right)(R - r + t) + \pi r \quad (9)$$

$$L = 2.57 \cdot (R - r + t) + \pi r \quad (10)$$

where:

R – radius of the outer tube [cm];
r – radius of the inner tube [cm];
t – fabric thickness [cm];
b – length of the connecting elements [cm];
x – overlap width when flattened the outer tube [cm];

l – width of flattened inner tube [cm].

As can be seen from equations (4), (5), (7), and (9), the total width of the 3D-woven fabric and the width of each component area depends solely on the initial data. This data includes the inner diameters (radii) and wall thickness of the two coaxial tubes.

2.2. Calculation of the number of warp yarns on each cross-sectional area

Flattened tubes represent a multilayer fabric in which, on each cross-sectional area, fabrics that are not connected to each other are superimposed. For each cross-sectional area, the number of fabric layers is shown in Table 1.

Table 1

Number of woven fabric layers/cross-sectional area

	Cross-sectional area				
	A	**B, B'**	**C, C'**	**D, D'**	**E, E'**
Number of woven fabric layers (N_s)	4	3	4	3	4

The structural characteristics of single woven fabric layer are considered known: the characteristics of the warp and weft yarns; the weave structure (weave repeat: Ru_1 and *Rb1* for warp/weft system, respectively); the densities of the warp/weft yarns (Pu_1 and Pb_1, respectively).

To calculate the total number of warp yarns on each cross-sectional area, the following steps are carried out:

A. Calculation of the number of warp yarns on a single woven fabric layer, for each sectional area, with the formula:

$$Nu_{1_i} = \frac{Pu_1}{10} \cdot l_i \tag{11}$$

where:
Pu_1 – the density of warp yarns on a single woven fabric layer (yarns/10 cm);
l_i – width of the cross-sectional area "i" (cm).

The number of warp yarns per cross-sectional area (Nu_{1a_i}) is adopted to be a multiple of the warp repeat of single layer weave structure (Ru_1).

B. The width of the cross-sectional areas is recalculated, using the formula:

$$l_{ia} = \frac{10 \cdot Nu_{1a_i}}{Pu_1} \qquad (cm) \tag{12}$$

C. Calculation of the total number of yarns per cross-sectional area, with the formula:

$$Nu_i = Nu_{1a_i} \cdot Ns_i \tag{13}$$

where:
Nu_i - the total number of yarns in cross-sectional area *"i"*;
Ns_i – the number of woven fabric layers in cross-sectional area *"i"* (indicated in Table 1).

The multiplying factor of the warp repeat, required to obtain the number of warp yarns for each cross-sectional area, is calculated with the formula:

$$f_i = \frac{Nu_i}{Ru_i} \tag{14}$$

where:
f_i – the multiplying factor of the warp repeat in the area of the cross-section *"i"*;
Ru_i – the warp repeat of multilayer weave structure in the area of the cross-section *"i"*.

2.3. Establishing the weft yarns insertion order

A shuttle weaving machine (equipped with one or two shuttles) would allow flawless weaving of this multilayer tubular structure, but it could also be done on a weaving machine for narrow fabrics.

Figure 3 shows three variants for the order of inserting the weft yarns on a shuttle weaving machine, represented for the symmetric tube flattening variant (Fig. 3-a, b, c) and for the asymmetric variant (Fig. 3-d, e, f). For the variants depicted in Fig. 3-a, b, d, e, the weft insertion is done with two shuttles. For the variants presented in Fig. 3-c, f, only one shuttle in needed.

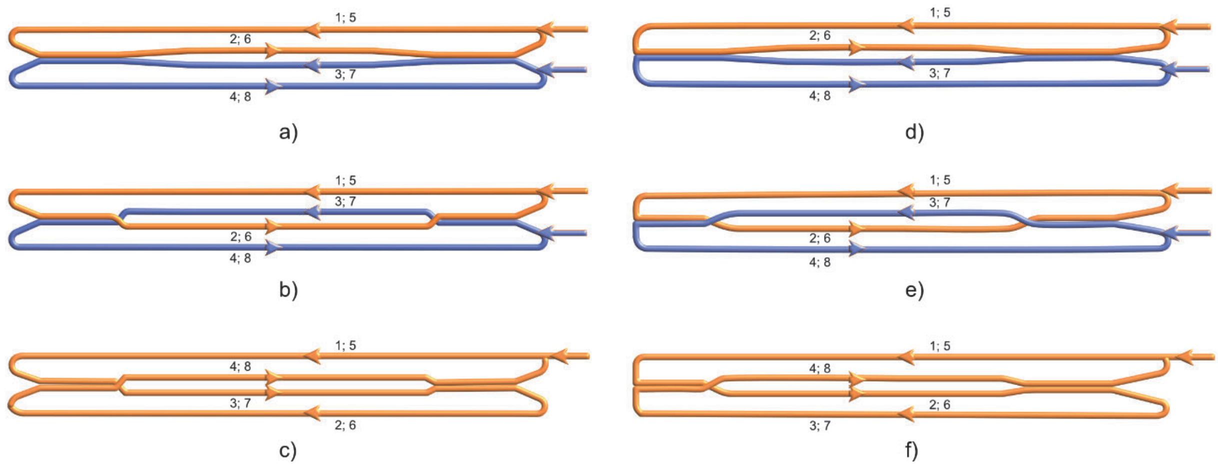

Figure 3. Different variants of the weft yarns insertion order, in symmetrical tubes flattening (a, b, c) and asymmetrical tube flattening (d, e, f)

The variants for the weft insertion order presented in Fig. 3-a and 3-d require weaving with two shuttles, but have the advantage that they can be woven with a lower total number of shafts than the variants in Fig. 3-b, e, c, f. The sequence of weft insertion on the four-layer woven fabric areas (flattened inner cylinder area and the outer cylinder perimeter surplus areas) is the same for the variants 3-a and 3-d. So, the warp yarns of these areas can be placed on the same group of shafts.

The variants presented in Fig. 3-c and 3-f can be woven with a single shuttle, but require a higher number of shafts to weave the four-layer areas of the woven fabric, because the order of weft insertion differs in these areas.

To ensure the correctness of the weave structure on the entire circumference of the outer tube, a number of warp yarns must be added for the variants presented in Fig. 3-a, b, c. The number of yarns depends on the weave structure adopted for tube wall and they must be placed on the opposite side of the selvedge from where the first weft yarn is inserted into the shed.

4 tension warp yarns (two on each of the fabric sides) should also be added to ensure that the warp yarns do not crowd at the edges, due to the return of the weft yarns. These tension warp yarns do not bind with the main structure and after weaving they are extracted from the tubes.

Once the weft insertion sequence is established, the weave patterns for each cross-sectional area of multilayer woven fabric can be made and then reunited within the same weaving diagram. The threading will take into account the multiplying factors established for repeating the weave on each cross-sectional area.

3. EXPERIMENTAL PART

A double tube was woven with 29.4 tex cotton yarns as warp and 166.7 tex (1500 den/192f) polyester filament yarn as weft. To validate the calculation algorithm, measurements of the width of the component elements were made and compared with the calculated dimensions. The initial design data were: the radius of the inner tube $r = 4.5$ cm; the radius of the outer tube $R = 8$ cm and the thickness of a single woven fabric layer: $t = 0{,}085$ cm.

Among the previously presented multilayer fabric variants, the variant with symmetrical flattening of the tubes and weft insertion with two shuttles was chosen (illustrated in Fig. 3-a). The dimensions of each area of the flattened tubes and total width of the woven fabric for this variant are shown in Fig. 4.

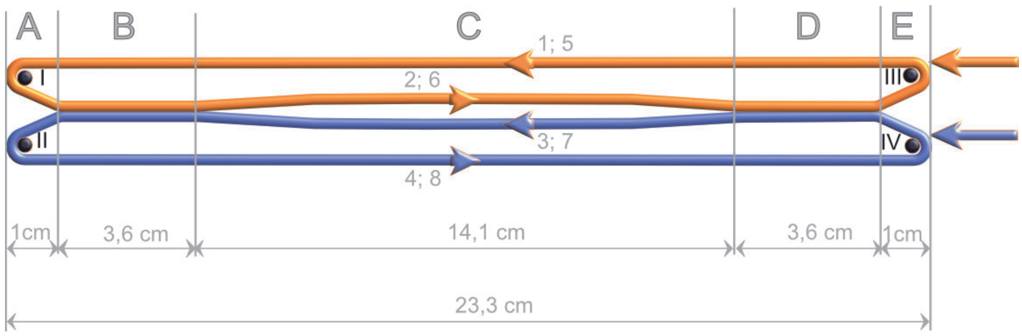

Figure 4. The dimensions in a flattened state of a symmetrically folded double tube.
I, II, III and IV - tension warp yarns

For the walls of the tubes, the plain weave structure was adopted. A compact double-layer woven fabric was chosen for the connecting elements between the tubes because it allows the weaving of multilayer double tubes with uniform densities for warp/weft yarn systems. In addition, it provides greater rigidity to the connecting elements.

Table 2 shows the basic structural parameters of double tube multilayer woven fabric for each cross-sectional area and total values.

Table 2

Structural characteristics of multilayer woven fabric

No.	Characteristics		Cross-sectional areas			Total
			A = E	**B = D**	**C**	
1.	Number of superposed woven layers/weave structure per layer		4 / plain weave structure	3 / plain weave structure; compact 2-ply woven fabric/plain weave structure	4 / plain weave structure	-
2.	Number of yarn systems	warp	4	4	4	4
		weft	4	4	4	4
3.	Density of yarns (yarns/10 cm)	warp	61	61	61	244
		weft	110	110	110	440
4.	Calculated width (cm)		1.02	3.59	14.13	23.34
5	Number of warp yarns/layer (calculated)		6.2	21.9	86.2	-
6.	Number of warp yarns/layer (adopted)		6	22	86	142
7.	Warp repeat multiplication factor		3	11	43	-
7.	Number of warp yarns		24 + (2*+4**)	88	344	568 (+6) = 574
9.	Recalculated width (cm)		0.98	3.60	14.09	23.27

*2 warp yarns have been added on the left selvedge, for a correct binding of the weft in the folding area

** tension warp yarns (2 on the left side and 2 on the right side)

For the chosen multilayer fabric, 18 shafts are needed (8 for areas A, C and E; 8 for areas B and D; and 2 shafts for the tension warp yarns). The reed count was 60 dents/10 cm and the denting was 4 warp yarns/dent. The weaving diagram is shown in Figure 5.

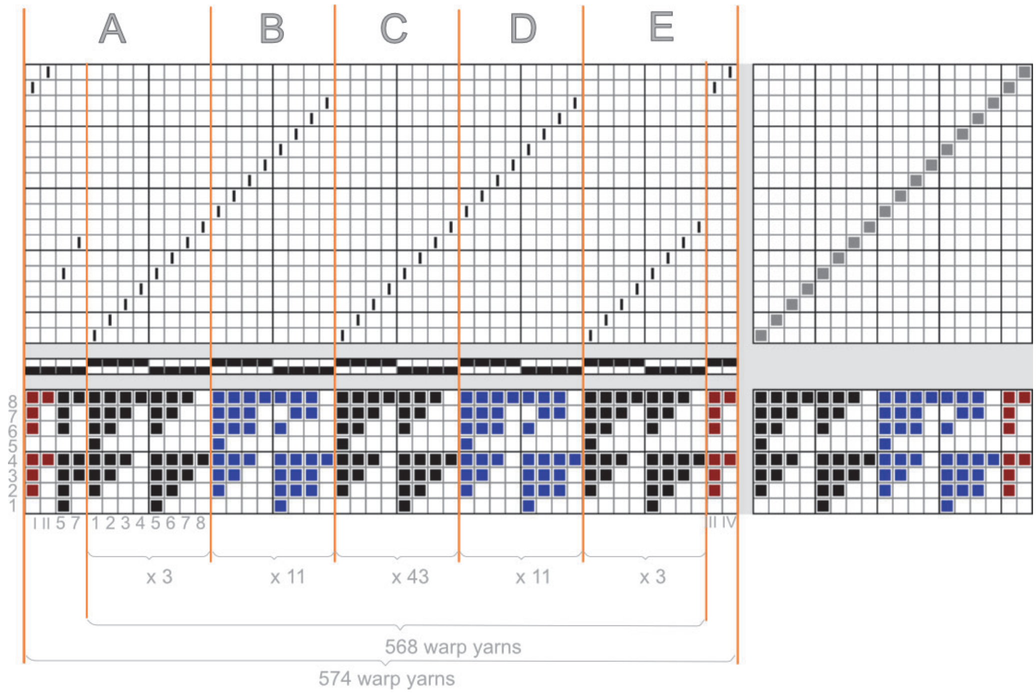

Figure 5. The weaving diagram for the multilayer woven fabric.
I, II, III and IV - tension warp yarns

The double tube was woven on an ARM Patronic loom equipped with 24 shafts, of which only 18 were assigned yarns, according to the weaving diagram. Figure 6 displays images of the weaving process (Fig. 6-a) and provides a detailed view of the tension warp yarns on the left side of the shed (Fig. 6-b). The double tube is shown unfolded and mounted on a rigid pipe in Figure 6-c, while Figure 6-d presents the same double tube with the annular area filled with textile waste.

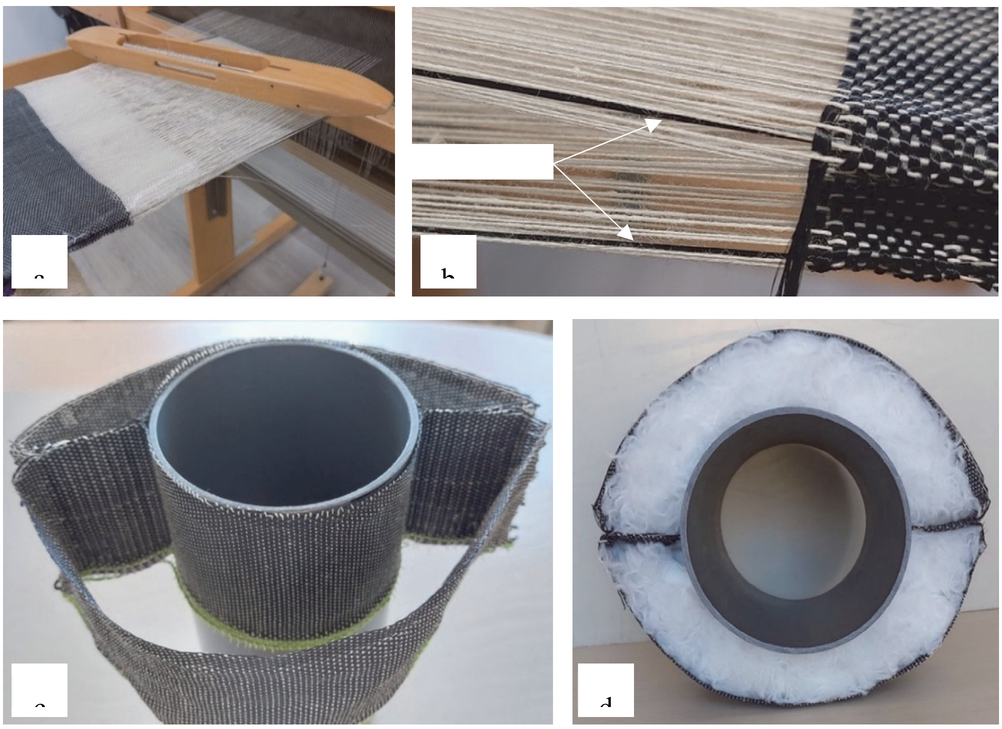

Figure 6. The weaving process of double tube multilayer woven fabric (a, b); the unfolded 3D woven fabric (c, d)

Table 3 presents the calculated, recalculated and measured width of each cross-sectional area and the total width of the multilayer fabric, together with the values of the deviations between the calculated width and the one measured on the fabric.

Table 3

Dimensions of the component areas of 3D-woven fabric

	A = E	B = D	C	Total (2A+2B+C)
Calculated width (cm)	1.02	3.59	14.13	23.34
Recalculated width (cm)	0.98	3.60	14.09	23.27
Measured width (cm)	1.00	3.50	14.10	23.1
Width deviation (%)	2	2.8	0.07	0.7

The deviation of the total width of the fabric from the originally calculated width is very small (0.7%). The deviations for the largest area (C) are insignificant (0.07%). The largest deviations were recorded for the connecting element, that defines the annular area (2.8%) and for area A (2%). Considering the small widths of these areas, even these deviations cannot be considered significant.

4. CONCLUSIONS

The paper presents the process of designing and manufacturing a double-walled tubular 3D-woven fabric in a single step using a conventional weaving machine.

An algorithm to determine the main structural parameters of the 3D fabric based on the inner diameters (radii) of the two tubes and the thickness of the tube walls was established.

After analysing the symmetrical and asymmetrical flattening of the tubes, as well as different variants of weft yarn insertion, the variant with symmetrical flattening of the tubes and weft insertion with two shuttles was selected. For weaving the multilayer fabric, 29.4 tex cotton yarn as warp and 166.7 tex polyester filament yarn as weft were used.

The measured dimensions of the tubular fabric were insignificantly different from the calculated dimensions, proving the accuracy of the design algorithm.

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EFFECT OF ADDITIONAL APPLIED VOLTAGE AND LASER BEAM POWER ON ELECTROSPUN NANOFIBERS

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***Abstract**. In this study we present a new improvement to the electrospinning process, a low-cost, simple and highly efficient method to produce nanofibers. One advantage of electrospinning is the morphology control of nanofibers. The setup proposed consists of one control ring placed along the jet trajectory and subjected to an additional applied voltage and three laser diodes (808 nm wavelength) positioned symmetrically around the needle of the electrospinning syringe and placed at an angle of 120 degrees from each other. We experimented with 900 mW diodes. A polyethylene oxide PEO (molecular mass of 900kD)-water solution prepared at 4 wt% was used in our experiments. A scanning electron microscope was used to evidence the effect of the two devices on the morphology of nanofibers. The analysis of the SEM images revealed that our approach is producing fibers having average diameters below 230 nm and a coefficient of variation (CV) of no more than 21%. Also, the obtained nanofibers were free of beads and presented a regular structure. Our setup combining control ring and laser diodes led to a decrease in the nanofiber compared to the diameter of the nanofibers obtained through traditional electrospinning. Therefore, the reduction in the average nanofiber diameter was of 11%.*

***Keywords:** electrospinnig, nanofibers, additional voltage, laser*

1. INTRODUCTION

The ability to shape materials using electrospinning process, reducing in this way the polymer fiber diameters from micrometers to submicrons or nanometers is important for many applications. When the diameters of polymer fiber materials decrease at nanometer level several outstanding characteristics (very large surface area to volume ratio, superior mechanical performance, flexibility in surface functionalities) appear comparing with any other known form of the material. These properties give the polymer nanofibers the possibiliy to be used in a broad range of technological applications in areas such as biomedicine, pharmacy, ceramics, composites, sensors, catalysis, filter, electronics and photonics [1].

In short, during the electrospinning process, the polymer solution is extruded from a spinneret to produce a small droplet due to a high electric field imposed between the nozzle and the collector. Under the influence of high voltage and the partially conductive solution, a Taylor cone forms and emits a thin jet that eventually results in nanofibers deposited on a collector [2]. Poly(ethylene oxide), PEO, is a low-toxicity polymer currently used in a variety of applications, such as pharmaceuticals. The polymer is often available in a variety of molecular weights ranging from 20,000 Da to several million Da. In terms of electrospinning, a long enough chain length is required for entanglements to form in solution to facilitate the formation of fibers rather than droplets. Thus, the large variety of molecular weights available for PEO can provide many options, but the main benefit of this polymer is its water solubility (due to its amphiphilic nature), providing a more sustainable and less hazardous route to nanofiber production. Also, the high dielectric constant of water (80.1) makes it particularly suitable for the production of reduced diameter fibers throught electrospinning process.

To get alignment of electrospun nanofibers, changing the single planar collector with face-to-face collectors is one of the options [3]. Dalton et al. utilized grounded rings to complete the preparation of aligned poly(ε-caprolactone) fibers [4] and Bazbouz et al. utilized two copper disks to obtain aligned nylon 6 nanofibers [5].

In our paper we present a new improvement of electrospinning process control based on our previous researches [6,7,8]. This new setup modulates the diameter of the resulting nanofiber.

2. EXPERIMENTAL PART

2.1 Materials

Polyethylene oxide (PEO) from Sigma-Aldrich with a molecular weight of 900 kD was used to prepare PEO solutions. 2 grams of PEO powder were added to 50 ml of deionized water in capped vials to prevent solvent evaporation. The solution was gently stirred under 30^0 C for 24 hours using a magnetic stirrer at 750 rpm.

The viscosity of the solution was measured at 23^0 C using Canon Instrument type Ubbelohde Viscometer, and the viscosity measurements were repeated three times. The electrical conductivity of the solution was performed using conductivity meter (Thermo Fisher Scientific OKCON 150).

Measured properties of the PEO solution include: kinematic viscosity 2450 cst/s and electrical conductivity 103 μS/cm.

2.2. Electrospinning process

The basic setup for electrospinning shown in Figure 1 is simple and the main components include a high-voltage power supply, a syringe pump, a spinneret and a conductive collector.

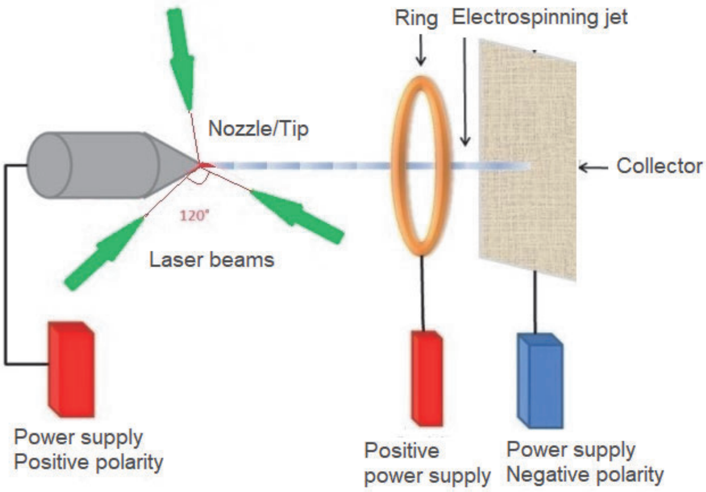


Figure 1. Electrospinning setup

The PEO solution was loaded in a glass syringe (10 ml) fitted with a steel needle size 21G. The syringe was fixed horizontally on the syringe pump (Model: KDS 100, KD Scientific) and the solution was electrospun on a rotating drum at 700 rpm by using a high voltage power supply type Matsusada HER 20R3 [9]. The rotatory collector was placed at a distance of 20 cm from the needle tip. A 20 kV voltage and a 0.7 ml/h feed rate were used during the electrospinning process. The relative humidity (under 45%) and temperature (22^0 C) were held constant during the experiments.

Our novel proposed improvement to the electrospinning process consists of a setup with two devices as follows: (i) one control ring having a diameter of 140 mm placed along the jet trajectory and subjected to an additional applied voltage of 5 kV and (ii) three laser diodes (808 nm wavelength). The ring was placed at a distance of 20 mm from the rotary collector. Also, the diodes were positioned symmetrically around the syringe needle at an angle of 120 degrees from each other, as indicated in Figure 1. Before the polymer jet initiation, the laser beams were focused in front of the electrospinning syringe tip. We experimented with 900 mW diodes. The idea is that the control ring allows a fine tuning of the field along the entire jet trajectory while the focused laser beams locally heat the polymer jet formed during the electrospinning process.

In order to highlight the effect of those two devices, four experiments were performed as follows: (i) no device, (ii) only the 5 kV control ring, (iii) only the three lasers diodes and (iv) the devices combination.

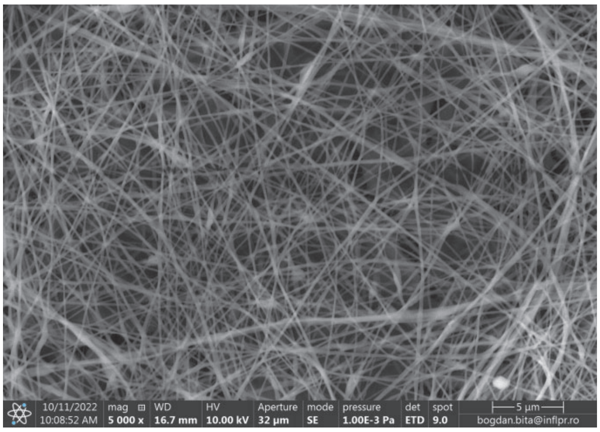
2.3. Characterization

Characterization of the nanofibers regading diameter and morphology was performed using a scanning electron microscope type ThermoFisher Apreo S. Forty measurements on random nanofibers using 5000x magnification images were preformed and average diameters are reported. The diameter of each nanofiber was measured with digital image processing software Image J.

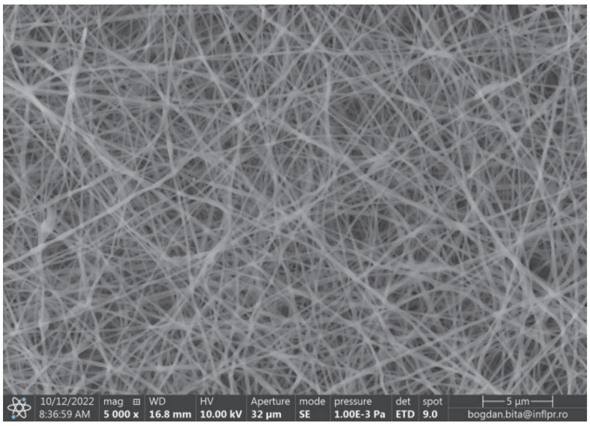
3. RESULTS AND DISCUSSION

We show that the electrospinning process with the combination of control ring and concentrated laser beam setup has a significant influence on the resulting nanofiber diameters.

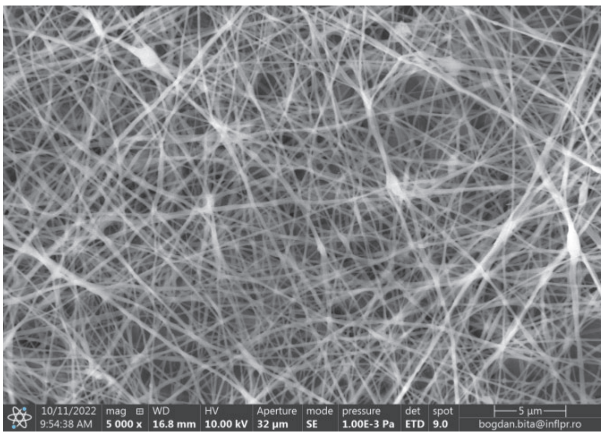
The SEM images at 5000x magnification of studied samples obtained during those four experiments (no devices, 5 kV control ring, 900 mW laser beams, 5kV control ring and 900 mW laser beams and) are shown in Figure 2.



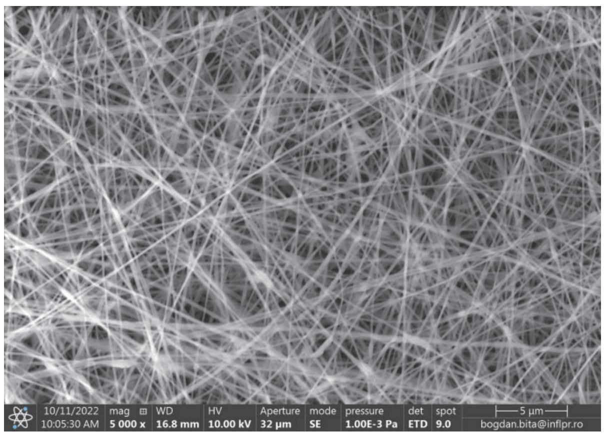
a) No device



b) 5kV control ring



b) 900 mW laser beams



c) Control ring and laser beam

Figure 2. SEM images of nanofibers

SEM images in Figure 2 reveal that electrospun nanofibers are free of beads and present a regular structure.

In Table 1 are given the spun fibers average diameter and its coefficient of variation noted with CV for each experiment performed.

Table 1

Average diameter

Experiment	Diameter	
	Average (μm)	CV (%)
1	0.19	30.9
2	0.22	18.5
3	0.19	17.5
4	0.17	21.0

The histograms of the 40 individual samples per experiment performed are shown in Figure 3. It can be observed that the PEO electrospun fibers have a narrow diameter distribution for all experiments, where most measurements are situated, except for a few outliers like in Figure 3.a and Figure 3.b.

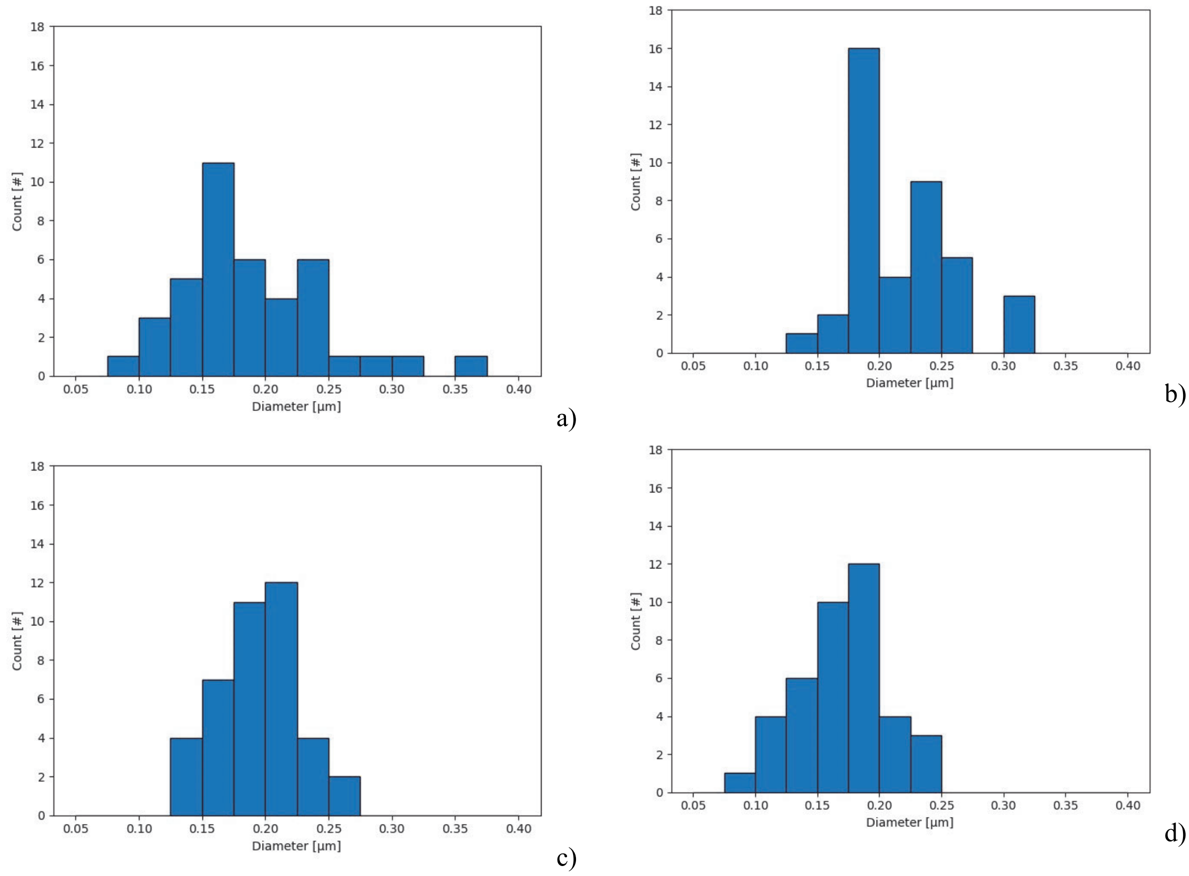


Figure 3. Histograms of PEO nanofiber diameters at different experiment: a) no device, b) 5kV control ring, c) 900 mW laser beams d) control ring and laser beams

In Figure 3.b, we can see that adding a ring to the basic electrospinning experiment, shown in Figure 3.a, reduces the variance in the diameter of the resulting fibers. However, the average diameter goes up from 0.19 to 0.22 micrometers. When adding a 900mW laser to the basic electrospinning setup, we can see from Figure 3.c that the variance gets reduced even more than before while the mean remains constant. The combination of the ring and the laser results in a much more stable manufacturing process, as seen in Figure 3.d. In this final setup, both the variance and the mean of the fiber diameter are significantly reduced compared to basic electrospinning experiment. In our experiments the electrically charged ring was used as an electrostatic "lens" that changes the shape of the macroscopic electric field from the jet initiation point to the collector target. The field lines thus converge to a central line above the collection target. When the charged jet passes through this field, it is forced toward the center in a manner analogous to “a stream of water pouring through a funnel” [10]. Moreover, the collection target has a potential bias whose polarity is opposite to that of the "lens" and the syringe needle [10]. This allows for a continuous increase in electric field strength as well as an increase in the downward force exerted on the jet as it approaches the collection target.

4. CONCLUSIONS

In this study we have presented a novel addition to the electrospinning process, which enables the fabrication of almost 11 % thinner PEO nanofibers compare to basic electrospinning. The new system consists in a control ring subjected to an additional applied voltage of 5 kV and of three laser diodes that both help to a fine tuning of the field long the jet trajectory and focus the polymer jet.

Further work will aim to investigate the using of more control rings and higher-power lasers as well as validate our method for other polymers.

Acknowledgements

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THE IMPACT OF TECHNICAL EMBROIDERY ON THE TEXTILE INDUSTRY: REVIEW AND PERSPECTIVES ON SMART TEXTILES

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Abstract. *Given the rapid expansion of the technical textiles sector, which stands as the primary locus of innovation and research within the textile and apparel industry, embroidery has emerged in diverse functional applications. This emergence is attributable to its distinctive capacity to fabricate three-dimensional lightweight structures and to apply threads onto the substrate material in a multidirectional fashion. Given the expansive nature of the smart textile's domain, which is inherently linked to technical textiles and wearable technologies, it is pertinent to categorize the principal applications of embroidery as technical domains. Within the realm of medical textiles, embroidery represents a relatively recent technique, yet it has demonstrated notable success in applications such as the development of wound dressings and the creation of pioneering solutions in tissue engineering. This success can be attributed to its unique capacity for fabricating intricate three-dimensional structures using delicate polymer materials. Another advantageous attribute inherent to products crafted through embroidery lies in the preservation of dimensional stability within the manufactured textile structures. Owing to these distinctive characteristics, embroidery finds extensive utilization in various technical applications, encompassing the development of heating grids, shielding mechanisms, conductive interconnections, as well as the creation of intelligent textile sensors and interfaces, among others. Furthermore, the versatility of materials and threads available for prototyping through this technique is noteworthy, including the application of conductive threads, metallic wires, laminated polymers, and carbon fibers, among others. Within the domain of intelligent textiles and smart textiles, especially in the context of healthcare applications, a particularly intricate sub-sector involves the research and development of textile sensors designed for the acquisition of biometric data and the measurement of various physical parameters. It is worth noting that most of these biosensors are realized through the transposition of fundamental principles into the textile structure. This study provides an overview of the broad applications of technical embroidery in the realms of smart textiles. These applications can be categorized into three primary groups: engineering, medicine, and smart textiles. Within the domain of engineering, embroidery plays a pivotal role in two key aspects: enhancing structural integrity and facilitating the creation of lightweight constructions. In medical applications, embroidery emerges as a critical technology, particularly in the development of implants. Nevertheless, this article concentrates its focus on the domain of smart textiles, an emerging field characterized by rapid growth and expansion, albeit relatively nascent in its development.*

Keywords: *technical embroidery, technical textiles, smart textiles, embroidered sensors, textile industry.*

1. INTRODUCTION

Smart textiles constitute a realm of interdisciplinary exploration that has garnered substantial attention across a myriad of industrial sectors. This heightened interest can be primarily attributed to their promising potential across a diverse spectrum of applications. One prevalent technological modality frequently harnessed in the pursuit of fabricating such innovative textiles is the utilization of embroidery. Embroidery, a time-honored artisanal craft renowned for its intricate ornamentation of textile substrates, enjoys a ubiquitous presence within nearly every global cultural milieu, its origins tracing back to antiquity.

With the advent of the Industrial Revolution, embroidery experienced a profound transformation, evolving into a mode of mass production, and concurrently expanding its technical horizons in tandem with ongoing technological advancements. To this day, embroidery remains one of the foremost techniques for augmenting the aesthetic allure of textile surfaces. It occupies an integral role in the realm of design, transcending across diverse fashion domains, including mainstream apparel, ready-to-wear collections, and haute couture, an enduring legacy spanning decades.[1]

Embroidery has currently permeated a multitude of utilitarian applications and holds a prominent position in the realm of technical textile production. Within this context, one of the foremost processing techniques rooted in embroidery technology is Tailored Fiber Placement (TFP), distinguished by its heightened demand. TFP is instrumental in ensuring the precise alignment of fibers or cords upon the substrate in a myriad of spatial orientations, facilitating the intricate fabrication of three-dimensional structures. This technique unveils extensive possibilities in the realm of structural and geometric design [2](Figure 1).

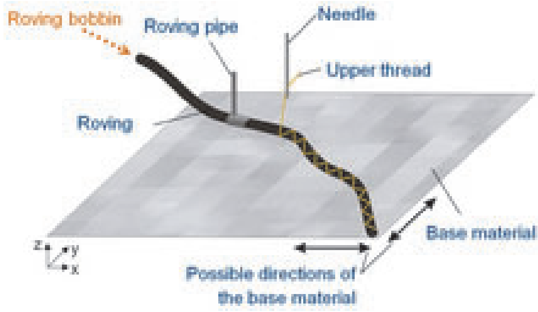

Figure 1. Sketch of the principle of the tailored fiber placement manufacturing process [3]

Another processing technique adapted for technical applications is chemical embroidery, which originally found its roots in the realm of machine-made lace manufacturing. Typically, this method involves embroidering a pattern onto a substrate comprised of water-soluble material or material that disintegrates upon exposure to heat. This particular approach is frequently encountered in various applications pertaining to tissue engineering, as well as the development of lightweight and reinforcement structures.

2. APLICATIONS OF TECHNICAL EMBROIDERY

Broadly, the technical applications of embroidery can be categorized into three principal domains: medicine, engineering, and smart textiles.[4]

The main application domains of technical embroidery, as well as the most commonly employed techniques in its execution, are presented below, in Table 1.

Table 1

Technical Embroidery Applications(4)

Application		**Structural element**	**Function**	**Technique**
Medicine	Regenerative Medicine	Cell distribution Cellular adhesion	Framework	3D embroidery incorporating Tailored Fiber Placement (TFP) and chemical embellishment techniques
	Wound dressing	Healing encouragement Wound condition monitoring	Wound-dressing material(bandaging) Textile biosensor	3D and 2D embroidery incorporating Tailored Fiber Placement
Engineering	Automotive	Composite textiles Fabric sensors Automative seat elements Textile communication interface	Lightweight structures Functional integration Structural health monitoring	3D and 2D embroidery by TFP
	Aerospace	Composite construction	Lightweight	3D and 2D embroidery by TFP
	Construction	Composite construction Textile sensors	Lightweight structures Reinforcement Structural health monitoring	3D and 2D embroidery incorporating Tailored Fiber Placement

Smart Textiles	Therapeutic approach and well-being	Actuators	Electrical stimulation Heat application	2D embroidery incorporating Tailored Fiber Placement
	Bio-sensing	Textile biosensors	Biomedical tracking and Biological feedback	2D embroidery incorporating Tailored Fiber Placement
	Physical perception	Textile sensors	Physical quantification	2D embroidery incorporating Tailored Fiber Placement
	Cross-functional	Wearable antenna Conductive pathways Sensing and actuation systems Soft electromagnetic coil Embroidered battery	Communication Interconnection Textile interface Electromagnetic induction Energy supply	2D embroidery incorporating Tailored Fiber Placement

Within the context of medical textile production and tissue engineering, embroidery finds multiple practical utilizations. While relatively nascent in this sphere, embroidery has already demonstrated its efficacy in advanced wound care and the fabrication of intricate 3D constructs from delicate polymer types, thereby contributing to innovative solutions in tissue engineering.

Embroidery also manifests its utility in the realm of engineering, embroidered reinforcement structures find utilization in fields such as construction, automotive, and aerospace engineering. Notably, reinforcements crafted using the Tailored Fiber Placement (TFP) technique exhibit distinctive aeolotropic properties attributable to the profound influence of fiber arrangement on the stress distribution within the constituent components. The physical characteristics of these embroidered structures can be characterized and modeled via methodical and mathematical computational methodologies.[3,5]

Lastly, embroidery stands as a cornerstone technology in the domain of smart textiles, playing a pivotal role in the advancement of wearable and flexible electronics. This application primarily revolves around the integration of conductive febrics and is commonly referred to as electronic embroidery or "e-broidery." Conductive yarns are employed for the interconnection of textile-integrated electronics, the creation of embroidered circuits, and the development of heating grids (11). Beyond its functional role in smart textiles, electronic embroidery has emerged as a vital solution in the realms of fashion and interior design, enabling the production of textiles featuring integrated LEDs. Moreover, ongoing research initiatives have unveiled promising prospects for employing embroidery technology in the crafting of textile antennas and coils for magnetic resonance sensors.[6,7]

Furthermore, the amalgamation of technological methodologies with the integration of conductive materials confers a wide spectrum of prospects in the realm of textile sensor development, particularly for biomedical and physical applications. Such applications encompass the evaluation of cardiac, muscular, and neural activities, as well as the precise measurement of pressure and strain [8,9]. The sensing attributes exhibited by textiles and textile-derived compounds hold considerable significance, notably in the domains of protective and medical functional clothing and textiles.[10]

3. TECHNICAL EMBROIDERY IN SMART TEXTILES

Technical embroidery emerges as a pivotal enabler, offering solutions for the realization of innovative products that find utility in an array of sectors, spanning from fashion and decorative textiles to technically advanced applications.

As elucidated earlier, smart textiles represent an expansive multidisciplinary research domain that converges the disciplines of design, textile technologies, electrical engineering, and information and communication technology. This convergence serves the overarching goal of devising novel products that align with distinct aesthetic, functional, and technical prerequisites.

3.1. Therapeutic approach and well-being

In recent years, there has been a notable surge in interest regarding smart textile solutions aimed at therapeutic approach and well-being The predominant advantage offered by smart textile technologies in the context of therapeutic applications lies in their capacity to facilitate wireless and uninterrupted treatment in non-hospital settings. Furthermore, textiles exhibit a lightweight profile and harbor a myriad of properties conducive to enhancing the physiological comfort of the wearer.

Embroidered actuators encompass heating textiles, a category with a diverse array of offerings already available on the market. Primarily, the concept of heating textiles finds application in the design of clothing, household textile products, and automotive seating**.** Figure 2 provides visual exemplars of embroidered heating textiles.

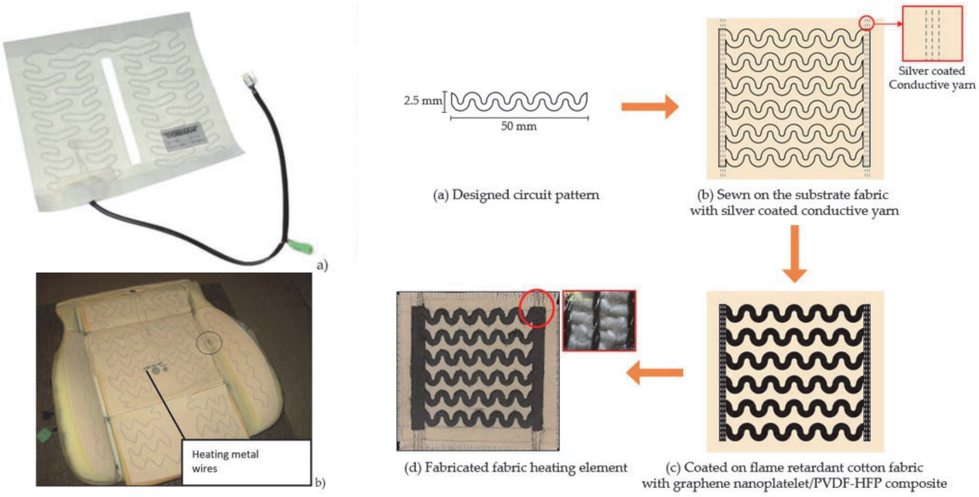

Figure 2. Examples of embroidered heating textiles [11,12]

Transcutaneous superficial electrical stimulation (TES) represents a widely adopted modality for addressing a range of therapeutic objectives, including the treatment of muscle atrophy, muscle strength enhancement, endurance training, pain management, functional movement therapy, and the restoration of motor function. The Keller research team has introduced an innovative TES technology predicated upon multichannel stimulation, affording the capability for real-time modulation of spatial and temporal changes in electric current density, both on the skin surface and within deeper tissue layers. This novel approach exhibits the potential to engender superior muscle selectivity and improved patterns of muscle activation when contrasted with prevailing TES systems that rely on fixed electrode placements.

The publication underscores the feasibility of eliciting precise extension movements in the fingers and wrists of poststroke patients, movements of sufficient force to counteract hyperactivity resulting from flexion.[13].

3.2. Bio-sensing

Wearable biopotential signal monitoring stands as a highly promising technology that has garnered substantial interest in recent years, primarily for its transformative potential within the realm of healthcare. This technology offers the prospect of continuous and non-invasive monitoring of human physiological signals, representing a notable departure from the unwieldy healthcare systems traditionally employed within hospital settings. Consequently, patients can now have their health status monitored conveniently in the comfort of their homes, and healthcare facilities and treatment can be enhanced in diverse locations, facilitated by the miniaturization of electronic devices [14]. Wearable electronics facilitate the longitudinal tracking of patients' health and enable vigilant oversight of their medical conditions over extended durations. Applications span a wide spectrum, encompassing the management of neuromuscular disorders, the mitigation of life-threatening cardiovascular conditions, muscle-building for athletic performance, addressing neurological abnormalities, and supporting rehabilitation initiatives. [15]

3.3. Physical perception

Textile sensors, designed to assess fundamental parameters like pressure, stress, temperature, and humidity, have found practical utility in structural monitoring and healthcare domains. A plethora of innovations, employing embroidery technology in tandem with conductive materials, have surfaced in this domain. The majority of these sensors are grounded in the estimation of physical attributes, such as electrical conductivity and capacitance. These attributes prove invaluable for appraising diverse physical and physiological processes, as well as environmental phenomena.

These sensors can only be effectively realized through embroidery or by implementing a hybrid approach that melds various manufacturing methodologies and techniques. This approach ensures the synthesis of distinct compounds or the attainment of specific finishing attributes requisite for sensor development.

Figure 1 illustrates a diverse array of wearable sensors grounded in textile substrates, a category that has garnered substantial commercial attention and progressively broadened its application domain. Notably, the integration of sensing functionality into textiles offers substantial advantages across a spectrum of fields, including but not limited to healthcare, sports performance, and military applications. These sensors hold significant potential for enhancing the overall quality of life and concurrently mitigating medical expenses. Furthermore, these sensors enable remote monitoring of personal health status and the physical condition of individuals, including athletes, soldiers, and more. [16]

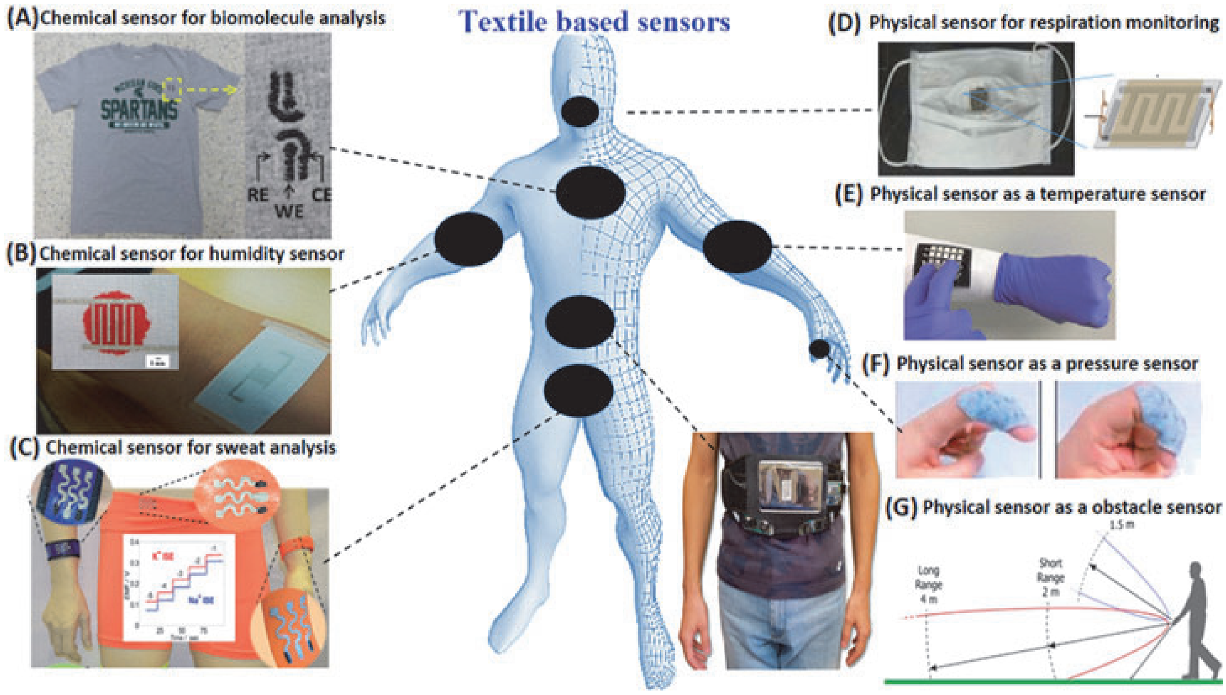

Figure 3. Applications of textile based sensors [16]

3.4. Cross-functional application of embroidery technology

The Tailored Fiber Placement (TFP) embroidery technology stands as a versatile method crucial for the establishment of electro-conductive interconnections, a critical requirement in the realization of smart products across domains like fashion, decorative applications, functional clothing, and technical textiles. The primary advantage inherent in this technology lies in its capability to facilitate extensive possibilities in the technical design of products by strategically positioning the electro-conductive cord along the substrate.

The utilization of composite materials across a diverse spectrum of industries, including aircraft, space exploration, shipbuilding, energy, construction, and mechanical engineering, has witnessed a consistent and noteworthy expansion in recent years. Presently, the domain of 3D reinforced composites is gaining prominence in the fabrication of components and structures composed of polymer composite materials (PCMs). These composites are crafted by utilizing 3D fiber preforms characterized by varied orientations and reinforcement angles, a process that inherently lends them the capacity to assume complex forms and geometries. In addition to conventional techniques like netting, 3D weaving, and knitting, contemporary methodologies for manufacturing 3D reinforced preforms incorporate the innovative Tailored Fiber Placement technology (TFP). This technique involves the deliberate deposition of reinforcing fibers (roving) onto a base material, following specified pathways in the x and y directions, executing a zigzag stitch pattern using an auxiliary thread. Subsequent to the meticulous arrangement of these layers with fiber strands, the resulting fiber preform is introduced into equipment where it is impregnated with a polymer binder and subsequently subjected to a curing process. [17]

Furthermore, the Tailored Fiber Placement embroidery technique fosters the advancement of various functional elements tailored for wearable and smart applications. This extends to the creation and production of electromagnetic coils designed for a diverse array of applications.

4. CONCLUSIONS

In conclusion, this article has provided a comprehensive exploration of the diverse applications of technical embroidery within the context of smart textiles. These applications have been categorized into three primary domains: engineering, medicine, and smart textiles. Within the engineering sector, embroidery plays a critical role in enhancing structural integrity and facilitating the creation of lightweight constructions. In the medical field, it emerges as a pivotal technology for implant development, often in conjunction with methods like electrospinning to achieve structures with optimal properties. Notably, this article has primarily emphasized the burgeoning field of smart textiles, characterized by its rapid growth and expansion. The innovative potential of embroidery technology in this context holds promise for continued advancements and breakthroughs in the realm of smart textiles.

Hence, it is evident that embroidery offers not only advantages for applied research but also holds substantial promise for facilitating technology transfer to industry by enabling efficient and uninterrupted production processes.

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FOOTWEAR USED TO IMPROVE THE QUALITY OF LIFE FOR DIABETIC PATIENTS

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Abstract. *This paper emphasizes the significance of customized footwear for patients with Diabetes Mellitus, especially those at moderate to high risk of foot ulceration. The use of specially designed footwear for these patients can play a crucial role in preventing complications and improving their quality of life. Concepts are also highlighted and confirm the need for research into the development of customized footwear for patients with Diabetes. By scrutinizing the factors that influence the quality of life of these patients and researching the importance of footwear, product design can be formulated to meet the specific requirements of this vulnerable group. The iCAD3D+ technology was employed to support the creation of footwear 3D models for the diabetic foot as this application allows the detailed development of virtual products based on which demonstrations and concept presentations of the models can be made. Additionally, this software grants designers the capability to visualize and refine the product at any stage of the design process, facilitating the creation of a personalized and comfortable end product. The development and application of custom footwear according to this protocol could have a profound impact on patients with Diabetes and peripheral neuropathy. It has the potential to reduce the risk of foot ulcers and subsequent complications, ultimately contributing to an improved quality of life for this patient group and their active engagement in a broad spectrum of activities.*

Keywords: *customized footwear, 3D models, diabetes mellitus, peripheral neuropathy.*

1. INTRODUCTION

Diabetes mellitus is a complex chronic condition that occurs when blood glucose levels exceed normal limits, leading to disturbances in glucose metabolism as well as protein and lipid metabolism. These dysfunctions lead to multiple effects on other organs and systems. Characteristic symptoms include intense thirst (polydipsia), frequent urination (polyuria), increased appetite and excessive food consumption (polyphagia), weight loss, vision problems, fatigue, tingling sensations in the hands and feet, skin infections, and others [1].

Early detection of diabetes is of crucial importance, as delay in seeking medical care increases the risk of complications. It is worth noting that diabetes can develop regardless of age, from birth to old age.

In terms of recognised types of diabetes, a general distinction can be made as follows:

- Type I diabetes (also known as insulin-dependent) mainly affects young people, but it can also occur in adults at a lower frequency. Causes include genetic or immunological factors, leading to the destruction of pancreatic beta cells, which are responsible for insulin production.
- Type 2 diabetes (non-insulin-dependent) affects people of all ages, including children, and is the most common form of diabetes. The onset of this type is associated with factors such as overweight/obesity, a sedentary lifestyle, and other metabolic disorders (high cholesterol, high uric acid, high blood pressure). The body gradually becomes insensitive to the insulin produced, requiring more insulin to assimilate glucose.
- Gestational diabetes occurs in pregnant women as a result of hormonal changes that cause insulin resistance. This type of diabetes usually disappears after birth, but both mother and baby are at increased risk of developing diabetes in the future.

- Secondary diabetes mellitus occurs as a result of other conditions or treatments, involving endocrine, liver, pancreatic disorders, etc.

Psycho-social factors often have a strong influence on self-management behaviours, and psycho-social variables, such as depression, may be better predictors of medical outcomes, including hospitalisation and mortality, rather than physiological variables and metabolic adjustments, such as presenting complications, body mass index (BMI) and haemoglobin A1c (HbA1c) levels [2]. There is also a belief in the medical field that different aspects of functioning and well-being contribute independently to overall quality of life, making the topic of quality of life a complex one that requires multidimensional assessment.

Overall, research indicates that people with diabetes have a lower quality of life compared to the general population. Analyses conducted by researchers show that patients with diabetes rated their quality of life as lower in aspects such as physical health, role fulfillment, and general perception of health. However, the differences were not significant in terms of social adjustment and mental health. A study in Sweden, which did not examine subgroups of diabetic patients (as defined by the characteristics of the disease), showed that quality of life was higher among controls than people with diabetes on most of the 12 aspects assessed, except for social health [3].

Research exploring quality of life in people with diabetes shows that the presence of complications, particularly two or more complications, is associated with a deterioration in quality of life. This is closely related to a significant increase in the risk of clinical symptoms of depression or anxiety among patients with any of the above types of diabetes. Currently, in Romania, about 2 million people suffer from diabetes. This metabolic disorder characterised by elevated blood glucose levels is slow to develop and often identified late.

Diabetic neuropathy can be defined by anatomical, clinical, neurological, and metabolic changes that occur during the progression of diabetes mellitus, after excluding other causes such as hereditary, traumatic, neoplastic, infectious, or autoimmune. This complication is the most common microvascular manifestation of diabetes. It is characterised by damage to neuronal glial cells, axons, and endothelial cells, with a prevalence ranging from 16% to 87%. As diabetes progresses, it is estimated that around 50% of patients will develop symptomatic neuropathy within 25 years following the onset of the disease. This condition is associated with significant morbidity, as patients with peripheral neuropathy have a 2-3 times higher risk of suffering falls and an increased risk of ulceration (15% will develop ulcers at some stage), infection, and even amputation (risk of amputation increases by up to 15 times). Diabetic neuropathy significantly affects quality of life, and up to 80% of patients diagnosed with neuropathy experience symptoms of depression or anxiety [4].

2. EXPERIMENTAL PART

In 1948, the World Health Organisation adopted a new perspective on health, stating that health is not only the absence of disease and infirmity but also includes physical, mental, and social well-being. People with diabetes often face challenges related to their illness and the demands of managing their condition daily. Patients must actively self-manage their diabetes every day, making a series of decisions in an attempt to achieve a metabolic state that is as close as possible to that of a non-diabetic person. The psychosocial impact of living with diabetes is often significant and can influence self-care behaviour and ultimately long-term control of blood glucose levels, increasing the risk of long-term complications and affecting the quality of life.

The authors of this article have developed the following scheme that highlights the factors used to measure the quality of life in people with diabetes (Figure 1).

Recent studies indicate that peripheral neuropathy has a prevalence of up to 18% in the pre-diabetic stages, suggesting that neuronal changes begin to occur at an early stage of glycemic imbalance, mainly through damage to thin nerve fibers. In type 1 diabetes, it is estimated that about 30% of patients will develop autonomic cardiovascular neuropathy within 20 years of disease onset, whereas in type 2 diabetes, this percentage can increase to 60% after 15 years of disease progression.

The diabetic foot is characterised by the presence of ulceration, infection, and/or deep tissue destruction, accompanied by neurological problems and possible varying degrees of peripheral vascular disease in the lower limb. This definition is in line with the criteria set by the World Health Organization and the International Diabetic Foot Task Force

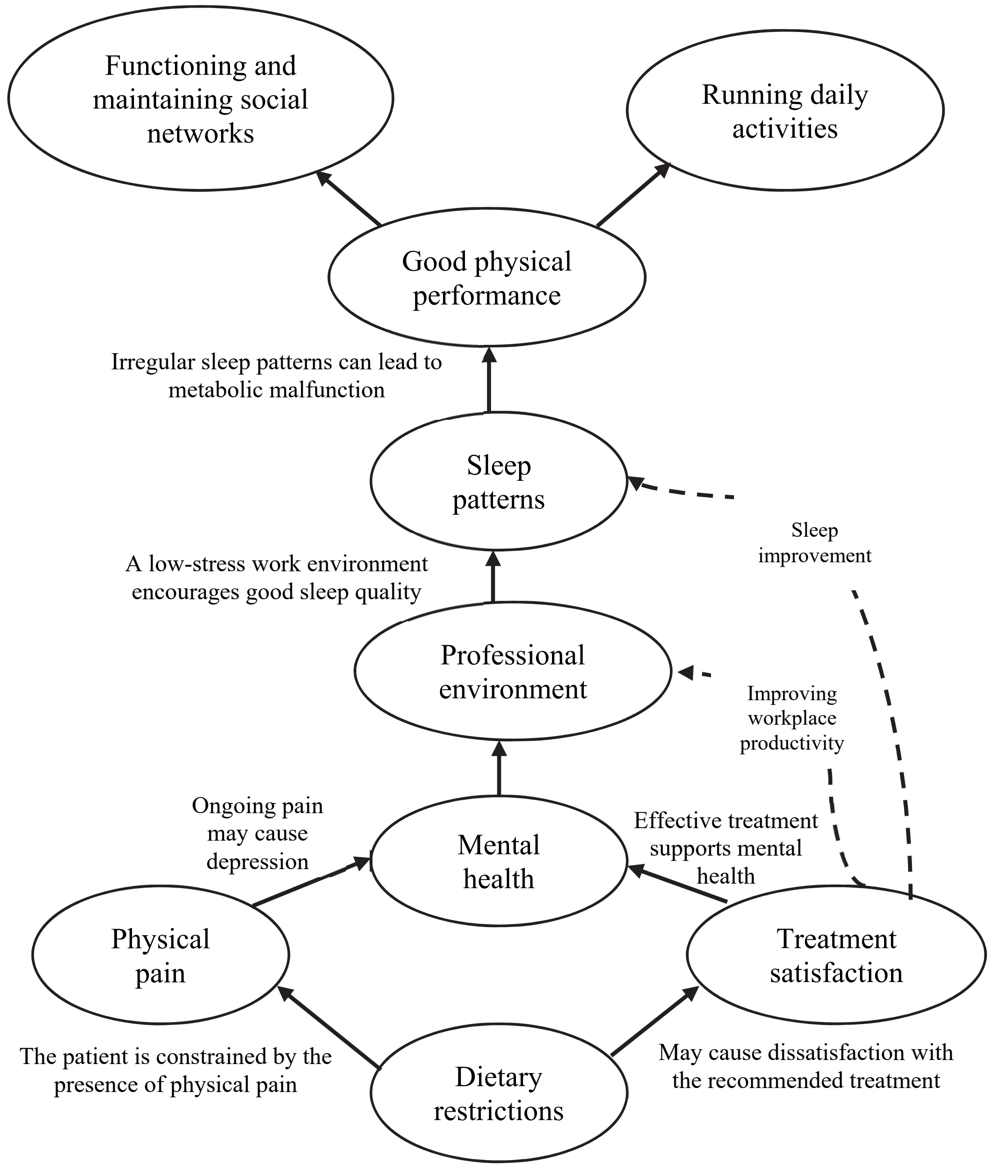

Figure 1. Factors used to measure quality of life in people with diabetes

Complications related to diabetic foot pathology are among the most serious consequences of diabetes mellitus (DM). These complications generate considerable suffering for patients and impose a significant financial burden on the healthcare system and society as a whole [5].

In patients with diabetes and affected by loss of sensation in the feet, wearing the wrong footwear and walking barefoot are the main factors leading to foot injuries and ulcers. Proper choice of shoe size is essential: shoes should be about 1-2 cm larger than your foot size and provide a comfortable fit without being too tight or too loose. In particular, the internal width of the shoe should correspond to the width of the foot at the metatarsophalangeal joints or the widest part of the foot. In addition, the height of the shoe at the toe should provide adequate room for all toes without causing discomfort or overlapping of the toes. It is recommended that the fit of the foot with the internal dimensions of the shoe be assessed from an upright, standing position, preferably in the afternoon when feet may be slightly swollen. If no commercially available footwear fits the foot correctly or if there are signs of abnormal pressure on the foot (such as excessive redness, calluses, or ulcerations), patients affected by diabetic foot complications should be referred for specialised footwear. This may include customised shoes, heels, or orthotics, tailored to the user's individual needs.

Among the types of diabetic neuropathy, the one of interest to this paper is also the most common, namely distal symmetric sensory-motor polyneuropathy, (75% prevalence), impacting mainly the sensory and motor systems of the peripheral nerves, affecting primarily the lower extremities, i.e. the legs and occasionally the hands. This condition is characterized by specific symptoms related to loss of nerve function, which include:

• Loss of sensation: One of the hallmark symptoms of this type of neuropathy is the gradual loss of sensation in the lower extremities. Patients may feel tingling, numbness, or burning sensations. This can lead to difficulty detecting extreme temperature changes or recognising tactile sensations such as touch or pressure.

• Pain: At a later stage of the condition, patients may experience chronic pain and discomfort in the affected extremities. These pains may be accompanied by prickling sensations or muscle cramps.

• Muscle weakness: Motor function may be impaired, leading to muscle weakness, especially in the legs. This can cause difficulty walking, moving, or maintaining balance.

• Balance and coordination disorders: As the condition progresses, patients may have difficulty maintaining balance and coordination, which can lead to gait impairment and potentially falls.

• Ulcers and infections: Loss of sensation can lead to unnoticed foot sores. These wounds can become ulcerated and may be prone to infection because patients do not feel the pain associated with the wounds.

• Trophic changes: skin and nail changes may also occur, such as dryness, thinning of the skin, slow nail growth, or calluses.

Elements such as the shape of the toecap, the shape and thickness of the sole in the ball of the foot, the shape and height of the heel must be taken into account in order to solve the main problem underlying foot pathologies in static and dynamic. For example, pointed toe shoe designs decrease the effectiveness of the winch effect created by the big toe, decrease the ability of the foot's sole to stabilise before initial contact with the ground, and cause excessive flattening of the longitudinal arch of the foot. The configuration of the midfoot area plays an important role in the biomechanics of the foot. This area comes into contact with the longitudinal arch of the foot via the gill.

All these factors point to the need for a new shoe design for diabetics, which is what the authors of this article have proposed.

3. RESULTS AND DISCUSSION

The proposed footwear designs were made using iCad 3D+ software which is a design tool dedicated exclusively to 3D footwear design and 2D footwear pattern engineering. It was developed by INESCOP (Spanish Footwear Research Institute). It represents a significant innovation in the field of footwear design as it integrates two distinct working environments, namely the 3D virtual medium and the 2D technical environment, which can be used in parallel and simultaneously. Basically, iCad 3D+ offers an advanced virtual solution compared to the traditional footwear design and engineering process. This brings with it multiple benefits, including a significant reduction in the time required for footwear product development as well as cost savings in both material and human resources for companies. By integrating these two frameworks, footwear designers can create and test virtual prototypes efficiently and accurately, helping to improve the footwear production process and reduce overall costs.

Orthopaedic Footwear is specifically designed to meet the medical needs of wearers [6] [7], but frequently the aesthetic requirements are neglected. Care for the patient is reflected in the quality of the products provided, and technologies to improve pressure relief and wear comfort. However, when considering quality of life issues, aesthetic and social considerations must also be validated to help the patient feel better and reduce negative psychological conflicts in their relationship with medical footwear.

Figure 2. 1st Design proposal

The first proposed design is an orthopedic shoe with a 4 cm high platform sole. The lightweight synthetic sole can be customised in colour and texture without affecting its weight. The toe cap has a square shape, slightly rounded at the edges to provide room for the toes to move and to avoid being too narrow around the toes. This prevents pressure in that area. The vamp and the quarters have perforations to allow air circulation so that the feet are kept ventilated. The padded areas on the footbed give the model cushioning when walking and facilitate mobility and stability while reducing overall foot trauma. The upper is made of leather and the interior is soft. The colour of the leather can be easily customised to suit the user's expectations.

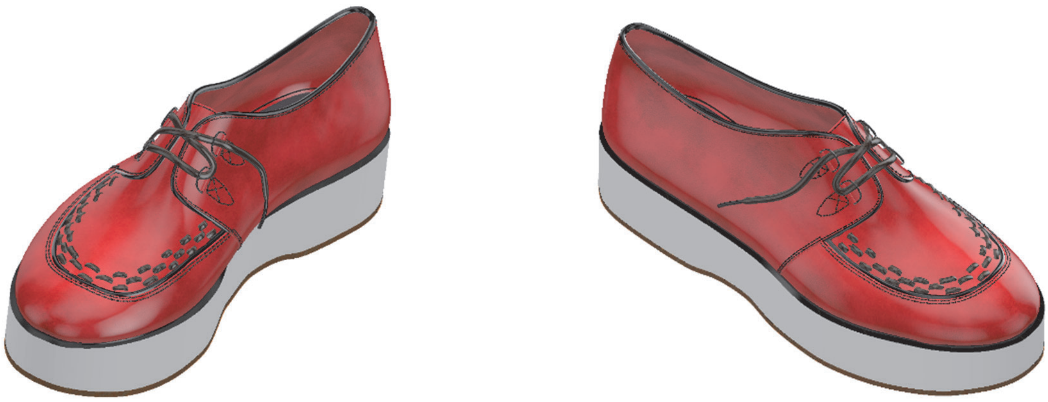

Figure 3. 2nd Design proposal

The 2nd Design proposal features an ultra-lightweight shoe with a flexible, strong, and slip-resistant sole for safe support while walking. A truly adaptable shoe thanks to the lace-up closure system for a perfect fit, it provides the necessary space for tired feet that are prone to swelling at the end of the day. The virtual model is created in leather but the design variant can be adapted with uppers made of knitted stretch panels for a better fit. Due to the construction option, more volume than standard is given to the footbed.

Figure 4. 3rd Design proposal

The 3rd Design proposal is a type of casual footwear that provides an adaptable fit on the foot, extra room for toe movement, and relief against pressure points. The upper assembly made from a combination of leather and knitted materials can expand throughout the day and allow the skin to breathe. The model is fitted with an anatomically designed insole and ergonomic sole for comfortable support when walking and cushioning on impact. The collar is padded, the inner lining is soft leather and the stitching overlap of the pieces avoids the bunion area or saddle bone deformity.

Figure 5. 4th Design proposal

The 4th Design proposal gives the wearer the comfort of a sandal with the added adjustability of Velcro closure with access on both sides of the shoe (inside and outside). An adjustable closure system is suitable for wide feet and bulky bandages. Ultra lightweight, flexible, strong sandals with slip-resistant soles for safe walking. The fit on the foot has a very wide margin of variability thanks to the straps on the upper that are easily adjustable to the wearer. The zig-zag stitch type eliminates hard stitch variations that irritate the skin and increase comfort for diabetic feet. The considered insole is thick and comfortable with a soft lining.

To verify the results, prototypes should be physically obtained and wear tested.

4. CONCLUSIONS

This paper highlights the importance of customised footwear for patients with Diabetes Mellitus, especially those with a moderate to high risk of developing foot ulcers. The use of specially designed footwear for these patients can play a crucial role in preventing complications and improving their quality of life. It also highlights concepts that confirm the need for research into the development of customised footwear for patients with Diabetes. By analysing the factors that influence the quality of life of such patients and researching the importance of footwear, it is possible to develop footwear designs that meet the specific requirements of this vulnerable patient group.

iCAD3D+ software technology was used to support the development of 3D models of footwear for the diabetic foot because this application allows the detailed development of virtual 3D models based on which concept demonstrations and presentations of the product can be made. This software also gives designers the possibility to visualize and adjust the product at any stage of the working process, thus contributing to a customized and comfortable final product.

The development and use of customised footwear according to this protocol could have a significant impact on the outcome of patients with diabetes mellitus and peripheral neuropathy. This could reduce the risk of foot ulcers and subsequent complications, helping to improve the quality of life of this group of subjects and engage them actively in a variety of social activities.

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EXPERIMENTAL STUDY ON THE INFLUENCE OF AIR GAP ON HEAT TRANSFER THROUGH MULTILAYER TEXTILE CLOTHING

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Abstract. In recent years, extensive research has been conducted on the thermal protection offered by clothing. The assessment of clothing's thermal protection performance (TPP) involves measuring the energy that passes through fabrics and air gaps trapped between layers of fabric. Several factors influence TPP, including external heat flux, fabric composition, and the thickness of air gaps. Air gaps play a crucial role in thermal protection, as air provides effective thermal insulation with lower thermal conductivity compared to textiles. While much research has focused on emergency scenarios involving flash fire exposures, firefighters more commonly face low-level radiant heat flux during routine or hazardous conditions, which can lead to burn injuries due to prolonged exposure. This study presents experimental results from an investigation into how air gaps in multilayer textile systems influence heat transfer and the TPP of clothing when exposed to thermal radiation in routine conditions. The experiments have demonstrated a significant enhancement in thermal protection performance when there is an air gap between the fabric and the sensor. Similarly, small air gaps trapped between the textile layers are beneficial. These findings underscore the importance of designing and optimizing the distribution of air gaps within the textile layers of thermal protective clothing as a crucial approach to enhancing thermal protection.

Keywords: *protective clothing, thermal protection, temperature, air gap layers.*

1. INTRODUCTION

Extensive research has been conducted in recent years to investigate the thermal protection provided by clothing. Evaluating the thermal protective performance (TPP) of clothing typically entails measuring the amount of energy that is transferred both through the textile materials and the space of air trapped between layers of fabrics. High values of the heat transfer rate can lead to burns.

Numerous researchers have investigated various factors that affect the TPP of fabrics. These factors can be categorized as follows [1]:

- The intensity of heat flux (external heat flux).
- The composition of the fabric, including raw materials, thickness, fabric density, and the presence of moisture.
- The air space between the fabric and the skin and between the layers of fabrics for the multilayer systems.

Among these parameters, previous investigations, including both bench-scale tests and flame-manikin tests, have highlighted the significant role played by air gaps in providing thermal protection. Air possesses excellent thermal insulation properties, with lower thermal conductivity than any textile material. However, it is important to note that simply increasing the thickness of the air gap does not necessarily result in improved thermal protection [2]. The effectiveness of thermal protection largely hinges on how heat is transferred through the air gap. The mode of heat transfer inside the air space can be conduction, radiation, or convection, and these modes of heat transfer are conditioned by the thickness of the air gap [3].

Regarding the external heat flux, based on Mäkinen's classification [4], thermal environments are categorized into three distinct groups:

- Routine: This category pertains to typical interventions for firefighters, characterized by relatively low radiant heat flux ranging from 0.42 to 1.26 kW/m² and air temperatures varying between 10 and 60°C.
- Hazardous: This category describes interventions where firefighters face high radiant heat flux ranging from 1.26 to 8.37 kW/m² and encounter air temperatures within the range of 60 to 300°C. In hazardous situations, firefighters typically have limited time available to carry out their tasks.
- Emergency: This category encompasses extreme conditions where the radiant heat flux escalates from 8.37 to 125.6 kW/m², accompanied by air temperatures ranging between 300 and 1000°C. In emergency scenarios, firefighters face critical circumstances and only have a few seconds to escape potential dangers.

While extensive research has focused on emergency conditions involving flash fire exposures [5], [6], [7] [8], [9], in many activities, the wearers of protective clothing (including firefighters) are more commonly exposed to low-level radiant heat flux. Burn injuries often occur in routine or hazardous conditions due to prolonged exposure [10]. However, limited research has been conducted on the thermal protective performance of garments during prolonged exposure to low-level radiant heat flux.

In this paper, experimental findings from a study investigating how the presence of air gaps in multilayer textile assembly affects heat transfer and, by extension, the thermal protection performance of clothing exposed to low-level radiant heat flux, are presented.

2. EXPERIMENTAL PART

2.1. Materials

At present, aramid textiles are widely employed in firefighter clothing due to their inherent exceptional thermal protective capabilities [3]. The protective garment selected to demonstrate the influence of air gap layers on thermal protective performance consists of an outer shell, thermal liner, and moisture barrier, respectively. Detailed information regarding the specific aramid specimens used and their fundamental properties can be found in Table 1.

Fabric thickness was tested with a Digital Thickness Gauge SDL Atlas according to ISO 5084/1996 and for surface weight, an electronic balance was used. The thermal resistance of the fabrics was determined using the Sweating guarded hot plate, in compliance with the standard ISO 11092/2016.

Table 1
Physical and thermo-physical properties of the monolayer fabrics and firefighter jacket

	Material	Surface weight, g/m^2	Thickness, mm	Density, kg/m^3	R_{ct} $m^2{\cdot}K/W$
Firefighter Jacket Assembly		540 ± 4	2.40 ± 0.04	224±5	0.0938 ± 0.0048
Outer shell	100 % Aramid woven	242 ± 2	0.5 ± 0.01	489 ± 5	0.0129 ± 0.0006
Thermal liner	100 % Aramid nonwoven	98 ± 2	1.46 ± 0.03	67 ± 2	0.0689 ± 0.0034
Moisture barrier	100 % Aramid knitted/ Polyurethane coated	195 ± 2	0.47 ± 0.00	418 ± 6	0.0134 ± 0.0034

2.1. Experimental apparatus and protocol

In most standard benchtop tests, the fabric is located horizontally over the heat source [1]. However, the orientation of the air gap between a garment and a human is almost always vertical in actual dressed conditions. For this reason, to perform the laboratory simulation of low-level radiant thermal hazards the standard EN ISO 6942/2002 - Protective clothing - Protection against heat and fire - Evaluation of materials and material assemblies when exposed to a source of radiant heat - was used (Figure 1).

Following this guideline, one should select incident heat flux density levels from the specified options: low level (5 and 10 kW/m^2), medium level (20 and 40 kW/m^2), and high level (80 kW/m^2). It is worth noting that alternative levels of incident heat flux density can also be considered [11].

In the tests carried out, we used this standard for routine conditions (1000 W/m^2) and a period of exposure of 2400 s, to simulate the exposure to low-level radiant flux for a long period. In this context, the specimens were subjected to testing, and the key parameter under observation was the temperature recorded by a calorimeter.

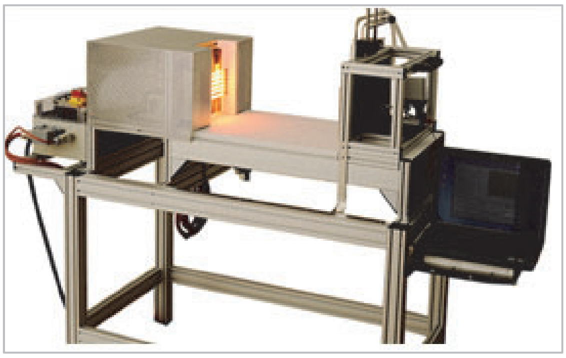

Figure 1. Standard EN ISO 6942/2002 [11]

Thus, the radiation source was positioned to provide a heat flux of 1000 W/m^2, and the temperature measurements were recorded via a Data Acquisition System connected to a computer running TESTPOINT software. The copper plate calorimeter is constructed from a rectangular copper sheet measuring 50 mm by 50.3 mm, with a thickness of 1.6 mm. It is bent along its longer dimension into an arc with a radius of 130 mm and has a mass of 36 g. Mounted on the back of the copper plate is a copper-constantan thermocouple. Behind the calorimeter, there is an air gap with a width of 9 mm, and an insulating board made of 14 mm non-combustible material. The tested samples measure (230 x 80) mm and the multilayer assembly mimics the configuration where the layers are used in practical applications. To fix the samples, clamps are used on the specimen holder, and a tension force of 2 N is applied. A protective shutter, situated between the radiant energy source and the sample, was employed to obstruct radiant energy before the exposure and to control the duration of exposure. Once the exposure period concluded, the protective shutter was closed to separate the sample from the heat source, after which a cooling-down period commenced.

The standard allows measurements to be made in two distinct conditions: transient and equilibrium. By evaluating specimens in both transient and steady-state scenarios, a comprehensive understanding of how these materials perform over time is provided and a more nuanced and thorough analysis thermal behavior of the materials is possible.

The procedure described by the standard EN ISO 6942/2002 for the source calibration was used. The standard offers two test options and in this study, we used method A. According to this method, the sample is supported in a free-standing frame (specimen holder) and is exposed to a specific level of radiant heat for a specific time. A schematic cross-section of the heat transfer model without any air gap between layers is given in Figure 2.

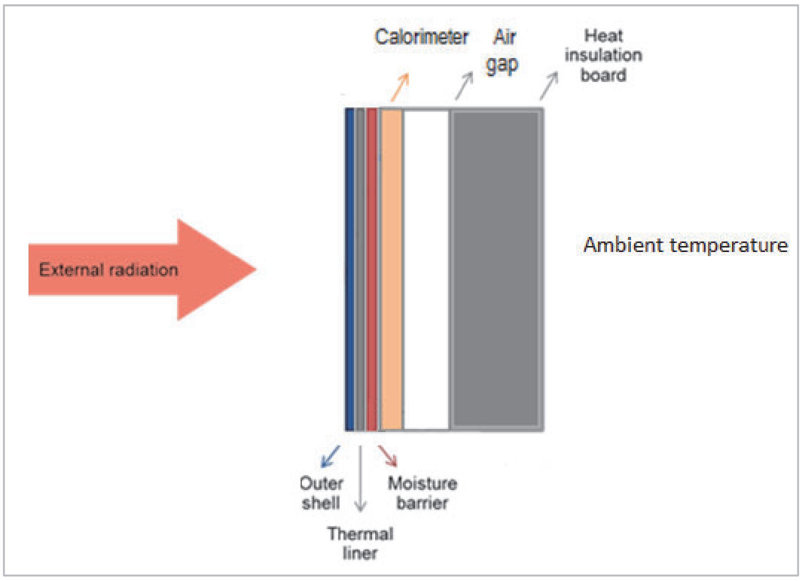

Figure 2. The schematic cross-section for the heat transfer model without any air gap

Acrylic plexiglass spacers were used to create the microclimate layer between the copper plate and the fabric. The spacers are 0.6 mm, 1.2 mm, 2.4 mm, 3.6 mm, and 4.2 mm thick respectively. A schematic cross-section of the heat transfer model with the air gap between the fabric and the calorimeter is given in Figure 3.

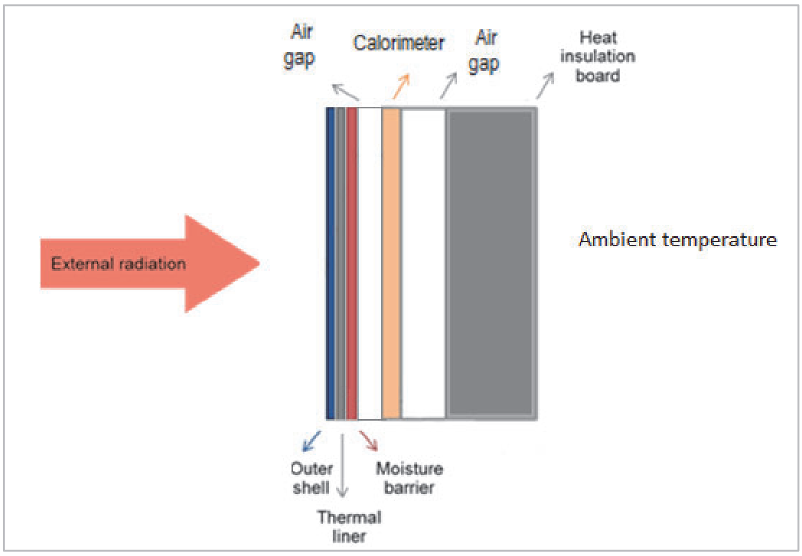

Figure 3. The schematic cross-section for the heat transfer model with an air gap between the assembly and calorimeter

To analyze the influence of air gap position on the heat transfer, the following experiment was performed. The air gap of 2.4 mm was taken as a reference, but it was distributed between the layers of textile material (two spacers of 1.2 mm each were used to form the two gaps). A schematic cross-section of the heat transfer model with the air gap between the fabric layers is given in Figure 4.

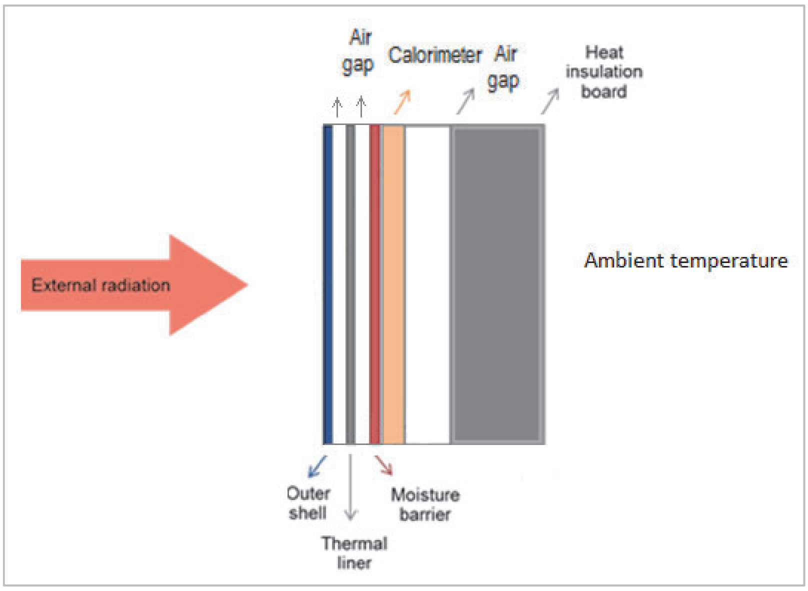

Figure 4. The schematic cross-section for the heat transfer model with an air gap between textile layers

3. RESULTS AND DISCUSSION

Figure 5 shows the influence of air gap size (thickness) on temperature. The findings revealed that the existence of an air gap reduced the heat transfer from the surrounding environment to the human body during routine conditions. Increasing the thickness of the air gap enhances thermal insulation because static air has lower thermal conductivity compared to fibers. However, if the dimensions of the gap are sufficiently large to allow for natural convection, the insulating properties of the air gap will be diminished. Many investigations of heat transfer through the air gap between the fabric and the test sensor have been the subject of extensive research, mainly due to the debate over whether a standard bench test should incorporate an air gap. For this reason, some standards (for example, ASTM D4108/1987) place the sensor at a certain distance, considering the thickness of 6.4 mm as the critical value at which the heat transfer mode in the air gap changes [12]. The non-uniformity of the air gap is influenced by the complexity of body shape and fabric properties.

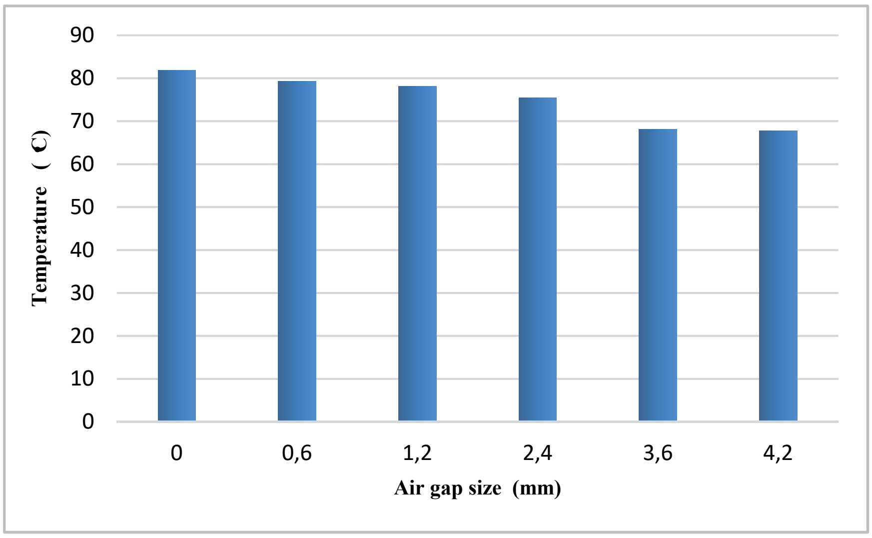

Figure 5. The influence of the air gap size on the temperature

Figure 6 gives the copper plate temperature variation for the multilayer system exposed to a radiant heat flux of 1000 W/m^2 without any air gap (model from Figure 2 - red line), and the copper plate temperature variation for the same multilayer assembly exposed to a radiant heat flux of 1000 W/m^2 but with an air gap of 2.4 mm between the last layer and copper plate (model from Figure 3 - blue line). The exposure time was the same in both cases, namely 2400 s.

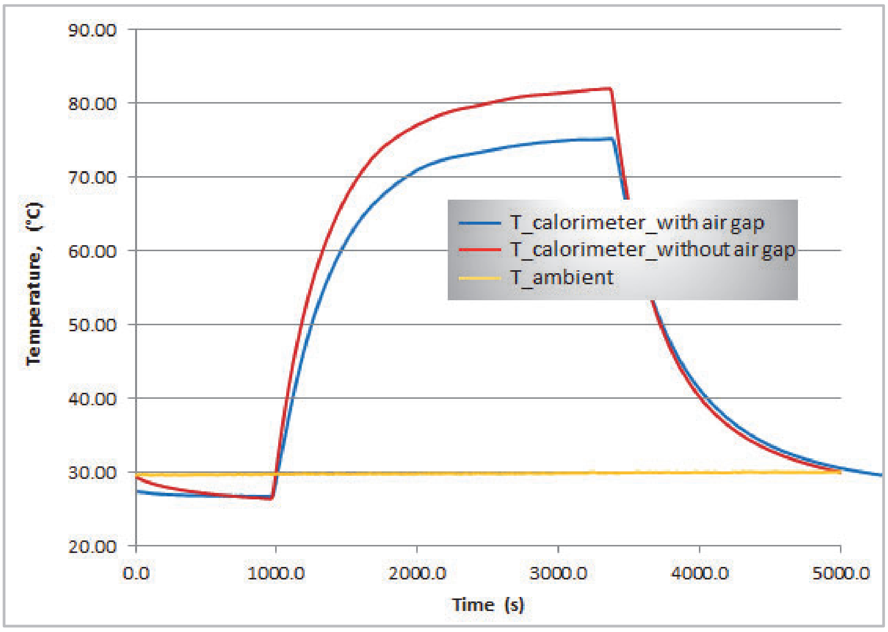

Figure 6. The temperature variation, for the multilayer system with an air gap of 2.4 mm between the fabric and calorimeter

When an air gap has been added, the temperature curve shows a lower rate of temperature increase during the exposure. It can be seen that with an air gap of 2.4 mm, the temperature is lower by about 6.5 °C. Once the heat exposure ceased, the temperature surpassed the ambient level, and the dissipation of heat into the surroundings led to a subsequent decrease. The cooling phase was characterized by an initial rapid temperature decline, followed by a more gradual and slower decrease.

The influence of air gaps between fabric layers within the three-layer assembly is shown in Figure 7. Figure 7 shows the copper plate temperature variation for the multilayer system exposed to a radiant heat flux of

1000 W/m^2, without air gaps between textile layers (model from Figure 2 - red line) and with two air gaps of 1.2 mm each after every textile layer (model from Figure 4 - blue line). It can be seen that two air gaps of 1.2 mm each, cause a temperature difference of about 9 °C. The exposure time was the same in both cases, namely 2400 s. The placement of the air gap had varying effects on the thermal insulation properties of multilayer fabric systems when subjected to the same test conditions. From this experiment, it appears that the air gaps distributed between the layers of multilayer clothing have a better effect on the TPP of clothing during exposure to low-level thermal radiation.

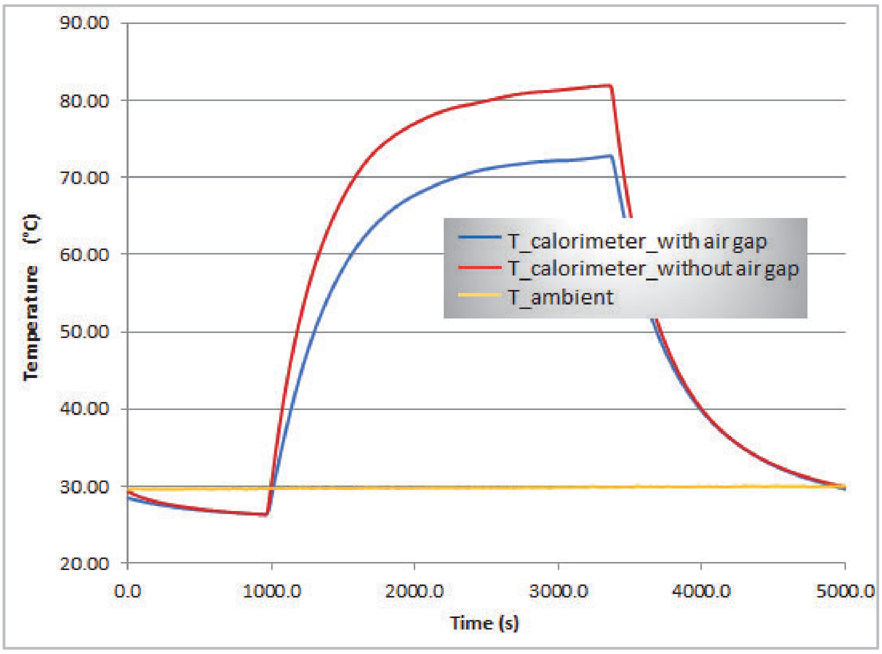

Figure 7. The temperature variation, for the multilayer system with two air gaps of 1.2 mm between layers

Given the expensive and time-consuming nature of these experiments, the obtained experimental data will be used to validate a heat transfer model for multilayer textiles exposed to low-level radiant heat flux.

4. CONCLUSIONS

In this study, we aimed to explore the impact of air gaps on the thermophysiological comfort of multilayer fabric systems in exposure to low thermal radiation. The findings showed that the existence of an air gap reduced the transfer of heat from the environment to the human body under routine conditions. Increasing the thickness of the air gap can enhance thermal insulation because static air has lower thermal conductivity compared to fibers. However, if the dimensions of the gap are sufficiently large to allow for natural convection, the insulating properties of the air gap will be diminished. The non-uniformity of the air gap is influenced by the complexity of body shape and fabric properties.

Additionally, we observed that the location of the air gap had varying effects on the thermal insulation properties of multi-layer fabric systems when subjected to the same test conditions.

Optimizing the distribution of air gaps inside multilayer protective clothing is a vital method for improving thermal protection. Parameters such as location and thickness can be used to describe the characteristics of the air gap.

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INVESTIGATION OF THE EFFECTS OF POLYMER TYPE AND FIBER ORIENTATION ON BURST STRENGTH OF THE TUBULAR SCAFFOLDS BY MULTILEVEL FULL FACTORIAL DESIGN

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***Abstract**. The replication of the native arterial structure holds significant importance in vascular graft studies. Besides their biological properties, the artificial vessels must possess sufficient mechanical qualities that align with the native blood vessels to withstand hemodynamic forces in the body and support biological functions. Burst strength is an indicator that shows the resistance of vascular grafts against blood pressure. Achieving adequate burst strength requires the precise determination and optimization of factors such as material selection and construction parameters including fiber orientation, wall thickness, multilayered design, and others. The effect of these parameters as interactions between them play an active role in final graft performance. In this study, polycaprolactone (PCL), poly(lactic acid) (PLA), and poly(L-lactide-co-caprolactone) (PLCL) are electrospun into 6-mm diameter tubular scaffolds under two different collector speeds, 200 and 10,000 rpm to obtain randomly distributed and radially oriented fibers and the impact of polymer type and fiber orientation on burst strength of the scaffolds is investigated. Statistical verification of fiber orientation and polymer type impact is carried out using a full factorial experimental design system. The results clearly demonstrate that these parameters, as well as their interactions, exert a statistically significant effect on the burst strength of the tubular scaffolds.*

***Keywords:** scaffold, electrospinning, burst strength, fiber orientation, full-factorial experimental design*

1. INTRODUCTION

In coronary artery diseases, mostly a bypass surgery is preferred as the treatment method, which is based on replacing the damaged or occluded vessel with an autologous vessel or a synthetic graft [1]. Although the use of an autologous vessel is the first choice, the procedure and patient's ability to recover are currently limited by issues such as dimensional incompatibility, donor morbidity, and dimensional degradation [2-3]. Vascular grafts are promising alternatives in this area for the healing of damaged tissue since they support the tissue formation and the production of extracellular matrix by providing mechanical strength, oxygen and nutrients in the cell microenvironment, and cell development [4].

Vascular grafts must conform to specific structural criteria, just like other tissue engineering applications, in order to resemble the target tissue. An optimal vascular graft should support cellular activities with its biocompatible structure, and also withstand the mechanical loads that the native vessel is subjected to [5]. Burst strength is one of the most crucial mechanical qualities since the vascular graft should be able to resist the dynamic blood flow. To prevent aneurysmal expansion, vascular grafts should have mechanical properties similar to those of native blood vessels and a burst pressure of roughly 2000 mmHg [6].

In all tissue engineering strategies, choosing the appropriate biomaterials is essential for improving the effectiveness of the regenerated vascular structure because they have an impact on the final scaffold's biocompatibility, biodegradability, toxicity, and long- and short-term mechanical properties in addition to providing cells a suitable environment to grow [7-8]. PCL is an ideal biomaterial for vascular grafts owing to its extended biodegradation period, adequate biocompatibility, and enhanced elasticity [9]. On the other hand, due to its excellent tensile strength and elastic modulus in addition to improved biocompatibility and biodegradability, PLA is also a widely utilized biopolymer for vascular constructions. However, the usage of PLA is constrained by its relatively low permeability to oxygen and water, high brittleness, polarity, and density, as well as inadequate heat resistance [10-11]. By combining the beneficial traits of their monomeric species while removing their unfavorable attributes, copolymers demonstrate the numerous advantages of hybrid materials, resulting in a synergistic copolymer final product [12]. PLCL is a copolymer of lactic acid and caprolactone in which the low level of stiffness of PCL and the brittle behavior of PLA are modified [13].

In addition to material selection, various constructional properties also play an important role in obtaining the desired graft structure. Due to its adaptable pore size and high surface to volume ratio, which allow for cell infiltration, proliferation, and oxygen/nutrient transfer, electrospinning has recently taken the lead as the technique of choice for vascular tissue engineering applications [14]. Furthermore, as the mechanical properties of scaffolds and cellular alignment are both influenced by the alignment of fibers in vascular grafts, fiber orientation has been regarded as one of the most important design criteria of the scaffolds [15-16]. Radially aligned fibers form a stiffer structure when stretched in the alignment direction and help resist burst load [17].

In this study, PLA, PCL and PLCL tubular scaffolds with both randomly distributed and radially oriented fibers are developed using electrospinning method. The main and interaction effects of polymer type and fiber orientation degree on burst strength are investigated with a multi-level full factorial design.

2. EXPERIMENTAL PART

2.1. Materials

PCL (Mn 80,000), PLA (Mn 230,000; Ingeo 2003 D with 4.3 mol% D-lactide content), and PLCL (70:30 Resomer® LC 703 S) are used as polymers whereas the solvent system components are chloroform (CH), acetic acid (AA), and ethanol (ETH). Sigma Aldrich is the supplier of all of the solvents and polymers.

2.1. Methods

2.1.1. Scaffold fabrication

PCL, PLA, and PLCL polymers are all dissolved in CH/ETH/AA (8/1/1 wt.) solvent system to produce scaffolds. For PCL and PLA, 8% wt. polymer concentration is employed, and 10% wt. polymer concentration is used for PLCL.

Custom-designed electrospinning equipment supplied by Inovenso, Turkey (Nanospinner, Ne100+), with a vertical feeding direction, a closed chamber and 0.6 mm needle tip, is used to develop PCL, PLA, and PLCL tubular scaffolds. In order to collect samples with randomly distributed (PCL_R, PLA_R, and PLCL_R) and radially oriented fibers (PCL_O, PLA_O, and PLCL_O), respectively, 200 rpm and 10,000 rpm are used in rotating rod collectors with a diameter of 6 mm. To produce continuous fibers, the voltage, feed rate, and tip-collector distances are kept constant at 11±1 kV, 2.5±1 ml/h, and 20 cm, respectively. After the fabrication, samples are left to dry for 24 hours to remove residual organic solvents then removed manually in tubular form for burst testing.

2.1.2. Burst strength measurement

In the majority of textile materials, surface burst resistance measurement is based on the principle of applying pressure to a linear surface [18-19]. However, in order to imitate the burst strength of the native vessel, this is achieved by exposing the tubular sample to pressure in vascular grafts. Therefore, a custom-designed burst test apparatus (Inovenso, Turkey) is used to measure the burst pressure characteristics of tubular scaffolds. Using the sleeves, the two ends of the tubular sample are fixed to the air nozzles and the sample is exposed to increased air pressure. The burst pressure measured at the point where the sample bursts is recorded. For the measurements, tubular samples are cut into 4 cm lengths, and each scaffold undergoes three test repetitions.

2.1.3. Statistical analysis

In this study, the general full factorial design method is applied to analyze the effect of 2 factors on burst strength. Minitab 16 Statistical Software program is used for statistical analysis. The factors and their levels are given in Table 1. While polymer type and fiber orientation are chosen as factors, burst strength response is specified. As presented in Table 1, the polymer type has 3 levels, while the fiber orientation has 2 levels. The significance of the results is defined by analysis of variance (ANOVA) analysis. In the overall full factorial design layout provided by the Minitab software program, there should be 6 trial runs. Since three replications is made for each design; 18 experiments are carried out in the experimental design (3x2x3=18).

Table 1

Parameters and levels used in the experimental design

Factors	**Levels**		
	1	**2**	**3**
Polymer type	PCL	PLA	PLCL
Fiber orientation	Radially oriented	Randomly distributed	

To determine whether the suggested experimental model is well predicted, ANOVA analysis uses the coefficient of determination (R-sqr) and adjusted coefficient of determination (R-adj) [20]. A p-value of 0.05 determines the statistical significance of the parameters of the suggested model; hence, factors with a p value less than 0.05 are thought to have an impact on the response [21].

3. RESULTS AND DISCUSSION

3.1. Burst strength

The burst strength values are provided in Table 2. It can be seen that samples with randomly distributed fibers display burst pressure values ranging between 730 and 791 mmHg. In contrast, it is evident that the samples with radially oriented fibers exhibit higher burst strength values, falling within the range of 1110 to 2199 mmHg. This clearly demonstrates the positive influence of fiber orientation on the burst strength of tubular samples as the aligned fibers provide better circumferential strength which is supported and confirmed by many studies in literature [23-25].

Table 2

Burst strength results of scaffolds with randomly distributed and radially oriented fibers

Samples	**Burst strength (mmHg)**	
	(_R)	**(_O)**
PCL	730.33 ± 94.50	1449.00 ± 22.91
PLA	737.67 ± 344.47	2199.67 ± 292.49
PLCL	791.75 ± 72.12	1110.67 ± 72.47

Additionally, the utilization of PLA significantly enhances the burst strength value. This outcome can be attributed to the enhanced mechanical properties of PLA. While PLA exhibits considerable mechanical strength, its rigid structure hinders it from attaining the necessary flexibility required for vascular grafts [26-27]. However, samples made of PCL and PLCL, known for their high elasticity [28-29], exhibit relatively lower burst strength values due to this inherent property.

In a study conducted by Johnson et al. (2019), it was suggested that an ideal vascular graft should possess a burst strength exceeding 1000 mmHg, similar to the human carotid artery [30]. Remarkably, the burst strength values of scaffolds with oriented fibers surpass this threshold, thus considered sufficient for their intended purpose.

This study's scope includes monolayer scaffold development. However, to morhologically, biologically, and mechanically resemble the native artery, it is crucial to build at least bilayer tubular scaffolds. The lower limits of the mechanical properties stated in the literature have been established for the final vascular grafts, and it is anticipated that when bilayer scaffolds, which will combine single layers developed within the scope of the study, are used, the burst strength of all grafts will exceed expected burst strength of 1000 mmHg.

3.1. Statistical analysis

The ANOVA analysis results obtained from the Minitab software program are presented in Table 3. According to the results, the sum of squares (SS) and p-values reveal that both the polymer type (p=0.002) and fiber orientation (p=0.000) have a statistically significant impact on burst strength values. Furthermore, the interaction between these two parameters also exhibits a significant influence (p=0.001). Upon examining the Sequential Sum of Squares (Seq SS) values, it becomes evident that the effect of fiber orientation on burst strength surpasses the impact of polymer type and the interaction between these parameters.

Table 3

The ANOVA response table of burst strength results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Polymer type	2	868726	868726	434363	11,51	0,002
Orientation	1	3138348	3138348	3138348	83,13	0,000
Polymer type* Orientation	2	1000654	1000654	500327	13,25	0,001
Error	12	453041	453041	37753		
Total	17	5460768				

When maintaining the same fiber arrangement, the burst strength values are found to be influenced by the choice of polymer type. For instance, when producing tubular scaffolds with radially oriented fibers, PLA exhibits a higher burst pressure of 2199 mmHg compared to PCL and PLCL, which have burst pressures of 1449 and 1110 mmHg, respectively. On the other hand, if the polymer type remains constant, the burst strength is then affected by the distribution of fibers. The main effect graphs for both parameters are illustrated in Figure 1(a), which allows to visualize their individual influences on burst strength.

Figure 1(b) represents the intersecting lines of the two factors, further confirming that burst strength is indeed affected by the interaction of two factors rather than solely influenced by individual main effects [25]. This interaction plot highlighs the complex relationship between these variables. It is known that the orientation levels vary among distinct polymers, even when the same collector speed is applied. For instance, due to their elastic nature, PLCL fibers undergo self-recovery after production, resulting in a crimped structure that also influences the fiber orientation level [31]. Consequently, they offer less resistance to applied forces, leading to a reduction in bursting strength. This reveals the common effect of both parameters observed in the interaction plot.

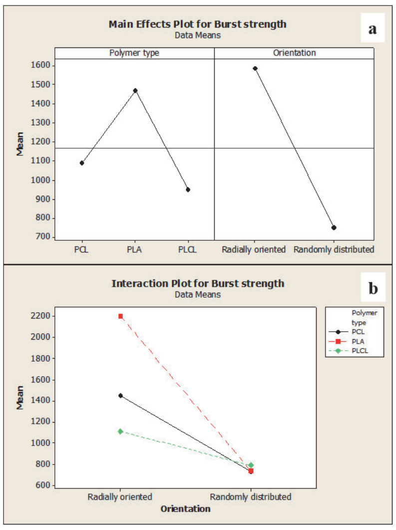

Figure 1. a. Main effects plots and b. interaction plot for the burst strength of tubular scaffolds

4. CONCLUSIONS

In this study, biocompatible and biodegradable polymers, namely PCL, PLA, and PLCL, are utilized to manufacture electrospun fibrous tubular scaffolds consisting of randomly distributed or radially oriented fibers. The primary objective of the research is to examine how the polymer type and fiber orientation influence the burst strength of the produced scaffolds. The findings indicate that both factors have a notable impact on the burst strength values. Specifically, using PLA with radial fiber orientation enhances the burst strength, while employing flexible polymers like PCL and PLCL with random fiber distribution leads to a reduction in burst strength. Importantly, the statistical analysis confirms the significance of these results and the effect of these parameters. In addition, it has been concluded that the design criteria have a common effect as well as an individual effect, that is, they are related to each other, and it is thought that it will be important to consider these bilateral interactions in the final properties desired to be obtained in vascular graft designs.

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DESIGN OF KNITTED FABRICS FOR ANTI-VIBRATION GLOVE LINERS

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Abstract. *People are exposed to vibrations from a variety of sources during their daily activities or work. The energy absorbed from these sources is radiated in the form of vibrations, some of which can cause occupational diseases that negatively affect worker performance and productivity. Among other protective equipment, various models of anti-vibration gloves have been developed. They consist of one or more layers of textile materials, especially knitted fabrics, combined with various impact-resistant materials such as silicone protrusions, foam, nubs, or rubber cavities filled with compressed air. The most commonly used textile materials consist of cotton yarns for the inner layers, high-performance yarns for the outer layer, and various elastic yarns to improve elasticity in the wrist or backhand area of the glove. Protective products such as anti-vibration gloves must be designed to preserve dexterity and the sense of touch when handling vibrating objects. An important aspect of designing materials to protect against vibration is knowing their natural frequencies. Failure to do so can result in resonance, a dangerous phenomenon that occurs during the use phase when the excitation frequency of an external force overlaps with the natural frequency of the system. This paper presents the characterization of interlock knitted fabrics, which could be used as linings for anti-vibration gloves, based on their measured natural frequencies. The free vibration method was used to measure the natural frequencies of the knits developed for potential vibration isolation applications. Fabrics made of cotton and cotton-bamboo blends with three degrees of stitch density were produced on large-diameter circular knitting machines with gauge 18E. Knitwear made from 100% cotton yarns (Ring and Compact) showed the highest values of natural frequencies. Knits made of 100% bamboo and the bamboo-cotton blends had natural frequency values about 25% lower than those made of 100% cotton. An important parameter is fabric thickness. As the thickness increases, the recorded natural frequencies decrease, which means that thicker materials are recommended for the development of vibration damping products, and the results confirm this conclusion.*

Keywords: *Vibrations, natural frequencies, knitted liners, anti-vibration gloves.*

1. INTRODUCTION

The human body is often exposed to vibrations emitted by power tools and industrial machinery, as well as vehicles such as trains and cars. This type of energy can emanate from hand tools, industrial machines, trains, airplanes, and automobiles and is emitted in the form of vibrations that can cause discomfort, reduced performance, interruption of activity, and even health and safety hazards. When the human body is exposed to vibration over a long period of time, it can have harmful effects on the vascular system, nervous system and musculoskeletal system. For example, vibrations generated by machinery are transmitted to the operator's seat, or from vehicles to the driver's feet, and then affect the entire body, known as whole-body vibration (WBV), which can lead to lower back and lumbar problems. In industry, there are many situations in which workers' hands are exposed to vibration, such as when using electrically and pneumatically powered hand tools (ballasts, chain saws, straight grinders, high-speed dental drills), known as hand-arm vibration (HAV). Exposure of the hand to such vibrations for too long can result in numbness, pain, peripheral neuropathy, and musculoskeletal problems of the hands and fingers. Complete neurological damage is irreversible and hand function is severely impaired [1-6]. Vibration isolating materials and anti-vibration gloves are commonly used to minimize vibration exposure. Common materials used as vibration isolators include elastomers, elastomer foam, elastic gel, cork, air bubbles, etc.

The essential characteristic of vibration isolators is their stiffness, which provides adequate load support, and their damping, which determines the mechanism of energy dissipation. The stiffness and damping functions can be provided by a single element or by different materials. Different materials may differ in stiffness, natural frequency, and damping characteristics to provide different vibration isolation properties.

2. ANTIVIBRATION GLOVES

The current design of anti-vibration products and gloves mainly focuses on the vibration isolation function when selecting materials. Increasing the thickness of antivibration materials can help improve their effectiveness in reducing vibration transmission. However, when used as an anti-vibration glove, the vibration isolating materials would also make it difficult to grip and control hand tools, which is a safety hazard. Therefore, it is important to use a material that has good vibration isolation properties while providing good comfort, thermal conductivity, air permeability, moisture wicking, and flexural softness [7]. In some available patents, models of anti-vibration gloves are proposed in which one or more layers are made of knitted fabrics, generally with various impact-resistant materials such as silicone protrusions, foam, nubs, or rubber cavities filled with compressed air. The most commonly used raw materials are cotton for the inner and core layers, high-performance yarns such as para-aramid, Kevlar, or high-density polyethylene for the outer layer, and various elastic yarns to improve elasticity in the wrist or backhand areas of the glove [8-12]. Protective products such as anti-vibration gloves must be designed to preserve dexterity and the sense of touch when handling vibrating objects. An important aspect of designing materials to protect against vibration is knowing their natural frequencies. Failure to do so can lead to resonance, a dangerous phenomenon that occurs during the use phase when the excitation frequency of an external force overlaps with the natural frequency of the system [13]. Factors affecting the potential effectiveness of an anti-vibration glove include how the risks of hand–arm vibration exposure are assessed, how the standard test for a glove is conducted, the frequency range and direction of the vibration for which protection is sought, how much hand contact force or pressure is applied, and the physical limitations due to glove material and construction. Finally, anti-vibration gloves cannot be relied upon to provide adequate and consistent protection for the wearer, and before considering their use, all other available means of vibration control should first be employed [14-15].

This paper presents an analysis of the measured natural frequencies of interlock weft knits that may be suitable for the lining of anti-vibration gloves.

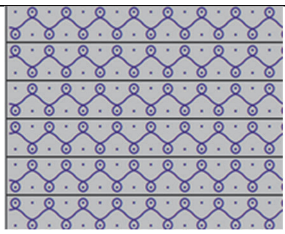
3. MATERIALS AND METHOD

3.1. Design of the knitwear

For the production of knitwear were used 100% cotton yarns obtained by two spinning processes: Ring and Compact, 100% bamboo yarns and bamboo-cotton yarns in a blend of 60%/40% and 70%/30%, respectively. Interlock fabrics were produced on both circular and flat knitting machines. Circular knit interlock fabrics were produced on an 18 E gauge and 30" diameter Fouquet circular knitting machine in three different strength values, tight, medium and loose, as shown in Table 1.

Table 1

Experimental knitted fabrics matrix

Interlock section rows	Yarns Nm 20/1	Stitch cam division settings		
		Tight	Medium	Loose
	100% Ring Cotton	3.2	5.0	5.2
	100% Compact Cotton			
	100% Bamboo			
	70/30% Bamboo/ Cotton			
	60/40% Bamboo/Cotton			

After the knitting process, the fabric samples were kept under standard atmospheric conditions for relaxation [16].

All variants were analysed and the structural parameters were determined: horizontal stitch density (wales/cm), vertical stitch density (courses/cm), stitch length (mm), mass per unit area (g/m^2), fabric's thickness (mm), according to the methods and standards presented in Table 2.

Table 2

Measured parameters and related standards [16]

Parameters	Related Standard	Measuring device
Courses/cm, Wales/cm	TS 250 EN 1049-2	Magnifying glass
Mass per unit area	TS 251	Scale
Thickness	TS 7128 EN ISO 5084	SDL Atlas M 034A digital thickness gauge

The values obtained for the dimensional characteristics of the fabrics are shown in Table 3.

Table 3

Dimensional characteristics of knitted fabrics [16]

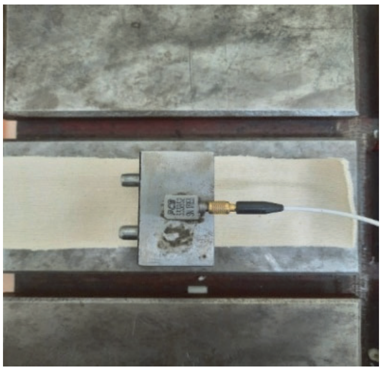
Sample code	Yarns	Stitch cam divisions	Stitch length (mm)	Stitch density		Thickness (mm)	Mass per unit area (g/m^2)
				cpc	wpc		
INT1-1	100% Ring Cotton	3.2	3.59	15.2	10.8	1.39	435
INT1-2		5.0	4.11	11.2	10.8	1.47	397
INT1-3		5.2	4.43	10.8	10.4	1.51	361
INT2-1	100% Compact Cotton	3.2	3.52	15.2	10.8	1.32	434
INT2-2		5.0	4.05	11.2	10.8	1.40	385
INT2-3		5.2	4.39	10.4	10.4	1.44	373
INT3-1	100% Bamboo	3.2	3.75	13.2	10.8	1.24	326
INT3-2		5.0	4.05	10.8	10.8	1.28	287
INT3-3		5.2	4.38	9.6	10.4	1.26	275
INT4-1	70/30% Bamboo/ Cotton	3.2	3.50	14.0	10.8	1.26	434
INT4-2		5.0	4.05	11.2	10.8	1.33	402
INT4-3		5.2	4.33	10.4	10.8	1.38	372
INT5-1	60/40% Bamboo/ Cotton	3.2	3.55	14.8	10.8	1.34	428
INT5-2		5.0	4.05	11.2	10.8	1.36	377
INT5-3		5.2	4.39	10.4	10.8	1.44	373

3.2. Measurement of the knitted fabric's natural frequencies

The dynamic behaviour of knitwear in a vibrating environment is evaluated in most cases by standardised methods, such as the method using vibration exciters (ISO 10819:2013). However, in recent years, we have conducted research to characterise the behaviour of knitted fabrics in a vibrating environment. This has involved the use of a well-known method of vibration generation by shock excitation, which is specific to the mechanical field, but has high potential for application to textiles. This method involves the determination of the free vibrations of an elastic system. Its measurement in the design phase of the system is considered a crucial step, since by knowing the frequency range of the system it is possible to avoid resonance phenomena in the operational phase.

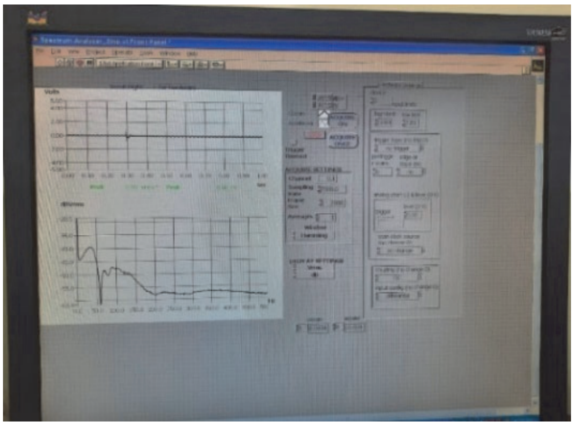
To analyse the vibration behaviour of a system, it is important to determine its natural frequencies, which are defined as the free vibrations that occur when an elastic system is removed from its equilibrium position. In the presence of frictional forces, mechanical energy is dissipated and the vibration is damped after a certain number of cycles. The frequencies are independent of the initial conditions of motion, and are therefore called natural frequencies of vibration [17].

In this study, the performance of knitted fabrics was evaluated by investigating the dynamic behavior of a metallic mass, placed directly to the surface of the knitted fabric by adhesive bonding, while the knitted fabric is attached to a fixed metal surface to avoid relative movements between the knitted fabric and the fixed metal surface (Figure 1.a). Since knitted fabrics are characterized by an anisotropic structure and different directional mechanical behavior, vibrations were generated and measured for each knitted fabric variant: walewise, coursewise and perpendicular on the surface [18]. The equipment used as exciter consists of an impact hammer Piezotronics and the vibrations were measured with an accelerometer PCB B52 Piezotronics. The signal is processed with an data acquisition card 6023 National Instruments. (Figure 1.b). To determine the natural frequencies of the system, the Fast Fourier Transform (FFT) was applied and the Spectrum Analyzer application of the LabView 8.2 software was used (Figure 1.c).



a. Metallic mass and accelerometer on the fabric

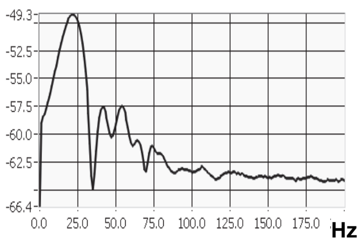
b. Data acquisition card



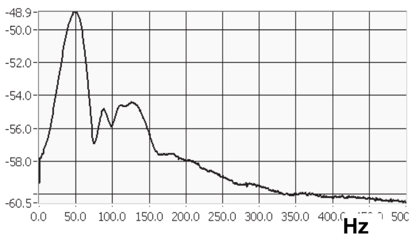
c. LabView software

Figure 1. Natural frequency measurement method [19]

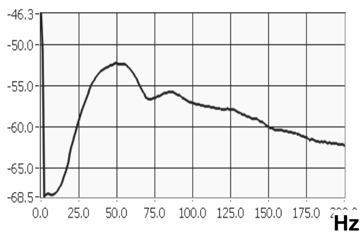
Vibrations are measured with a PCB Piezotronics accelerometer and the signal is processed by a data acquisition system. Frequency spectral analysis is the basis of any diagnostic procedure that uses vibration measurement and consists of decomposing the signal into a sum of frequencies, each corresponding to a particular vibration level, by applying the fast Fourier transform (Figure 2) [19].



a) Coursewise



b) Walewise



c) Perpendicular

Figure 2. Recorded natural frequencies of knitted fabrics

Each curve is composed of a certain number of waves, where the highest peak of the first wave in the horizontal direction is the natural frequency of the material, measured in [Hz]. The magnitude of the natural frequency for each material provides information about its stiffness. The higher the natural frequency, the higher the stiffness of the material is estimated to be [18].

4. RESULTS AND DISCUSSIONS

4.1. Influence of the test direction on the natural frequencies

Figure 3 shows an example of the natural frequencies of the tightest group of fabrics and displays the frequency level for each of the five raw materials. This is comparable in the transverse and longitudinal directions, and approximately three times higher in the perpendicular direction, regardless of the machine division. Thus: 100% Ring Cotton knitted fabrics show values in the range (31-52) Hz in the course direction, (32-52) Hz in the wale direction and (95-146) Hz in the perpendicular direction; the 100% Compact Cotton knitted fabric recorded values in the range (34-44) Hz in the row direction, (32-40) Hz in the wale direction and (92-140) Hz in the perpendicular direction; the 100% Bamboo knitted fabrics have values in the range (28-40) Hz in the row direction, (32-37) Hz in the wale direction and (80-106) Hz in the perpendicular direction; the 70/30% Bamboo/Cotton knitted fabric have a range of (28-36) Hz in the row direction, (25-32) Hz in the course direction and (75-116) Hz in the perpendicular direction; the 60/40% Bamboo/Cotton knitted fabric recorded values in the range (22-52) Hz in the row direction, (26-38) Hz in the course direction and (83-117) Hz in the perpendicular direction.

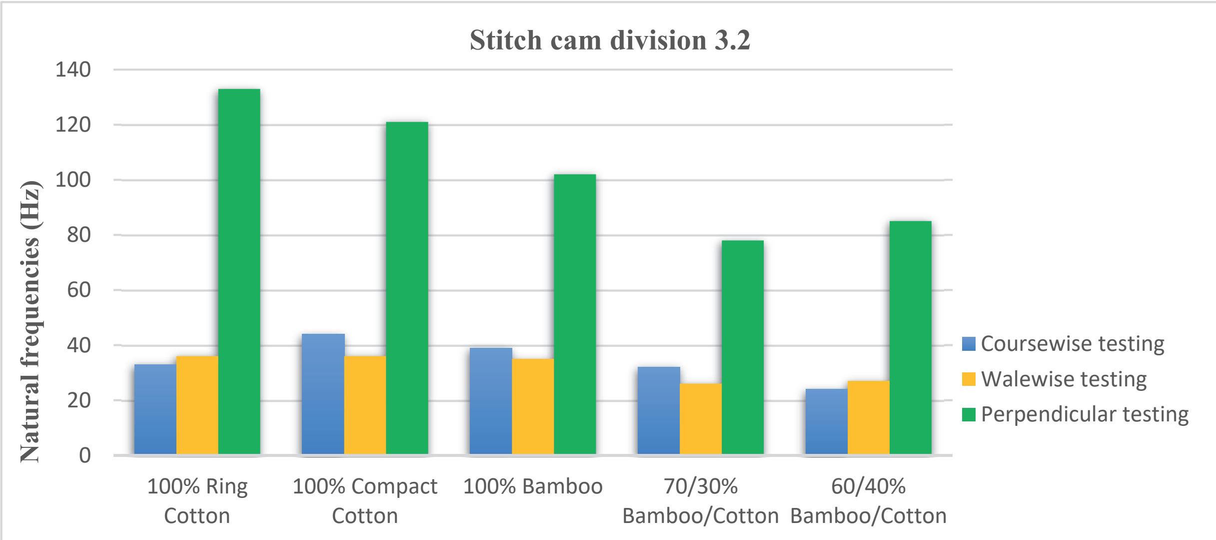


Figure 3. Measured natural frequencies on different test direction

In this investigation, the influence of the test direction on the recorded natural frequencies was confirmed again, which had already been investigated previously [12, 18].

4.2. Influence of the tightness on the natural frequencies

Stitch cam depth given by its different divisions affects the value of stitch length and stitch density, which have the greatest effect on the properties of the knitted fabric, such as: dimensional stability, weight, comfort, mechanical properties. In circular weft knitting machines, the strength of the knitted fabric can be adjusted by the position of the stitch cam, the higher the machine division, the greater the stitch length, the looser the knitted fabric.

When analysing the results for interlock knitted fabrics, shown in Figure 4, it is noticeable that all knitted fabrics have higher values for natural frequencies at stich cam division of 5.2 than at a value of 3.2, which is an opposite response, as expected, while at value of 7.2 there is a significant decrease in natural frequencies, which is an expected phenomenon. Bamboo 100% is the only row material that does not follow this rule, which can be explained by the properties of the yarn.

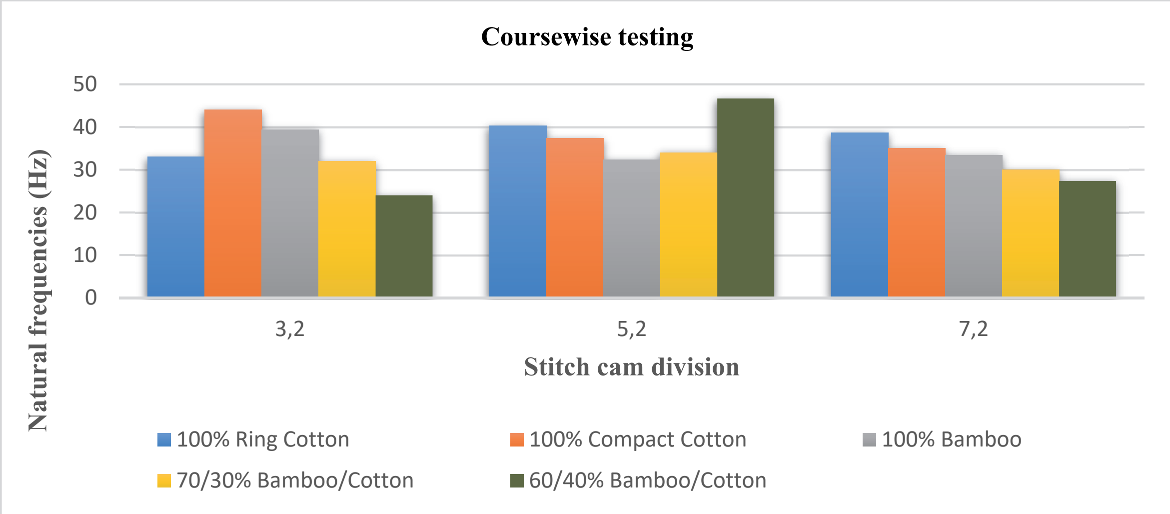


Figure 4. Natural frequencies of different fabric's tightness

4.3. Influence of the thickness of the fabric on the natural frequencies

Decreasing the glove cushion stiffness and optimizing its damping can increase the glove isolation effectiveness [20]. This can be achieved by using softer materials, or increasing the thickness of the glove material at its palmar side. It is well known that material thickness has a direct influence on vibration behaviour, as numerous studies have proven that as thickness increases, the recorded natural frequencies decrease, meaning that thicker materials are recommended for the design of vibration control products. However, these two solutions are limited, because: it is difficult to effectively control a vibrating tool if the glove contact stiffness is too low and when the glove thickness is beyond a certain point, the glove will not be wearable for practical applications because it is too bulky to grip [21].

The ISO 10819:2013 standard also specifies the 8 [mm] a maximum thickness of the material in the palm of an anti-vibration glove and also at the fingers, although the transmissibility of the glove is only tested at the palm [14].

The results of the measurements performed on the current group of knitted fabrics are shown in Figure 5. The diagram shows that the natural frequencies of both 100% cotton knitted fabrics (Ring cotton and Compact cotton) and 100% bamboo knitted fabrics decrease with increasing thickness. For knitted fabrics made of bamboo/cotton blends, this rule does not apply. It can be concluded that the type of yarns used is important and that their properties should be determined to explain the phenomenon. This will be pursued further by the authors.

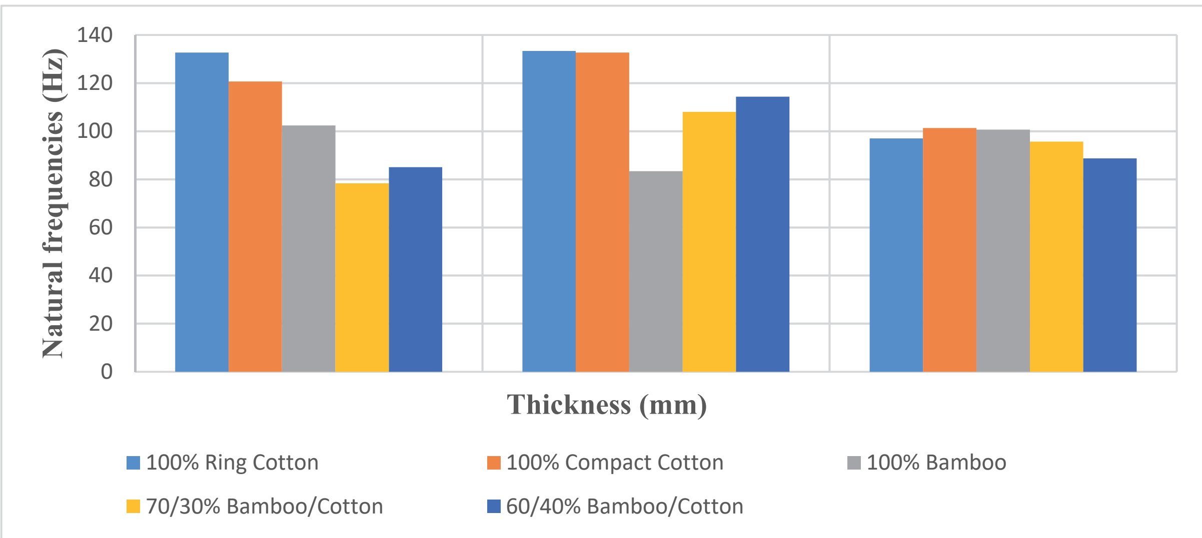


Figure 5. Natural frequencies of different fabric's thickness

It has been demonstrated that a thicker fabric provides better vibration isolation due to its lower isolation frequencies [22].

It is concluded that fabric thickness is one of the control parameters for protection against vibrations, but it is adjusted within the limits set by the technical characteristics of a given knitting machine.

4.4. Influence of the yarn type on the natural frequencies

For this group of knitted fabrics, analysis of the data obtained in the perpendicular test direction i.e. (Figure 6) shows that the 100% cotton knitted fabrics (Ring Cotton and Compact Cotton) have the highest natural frequency values.

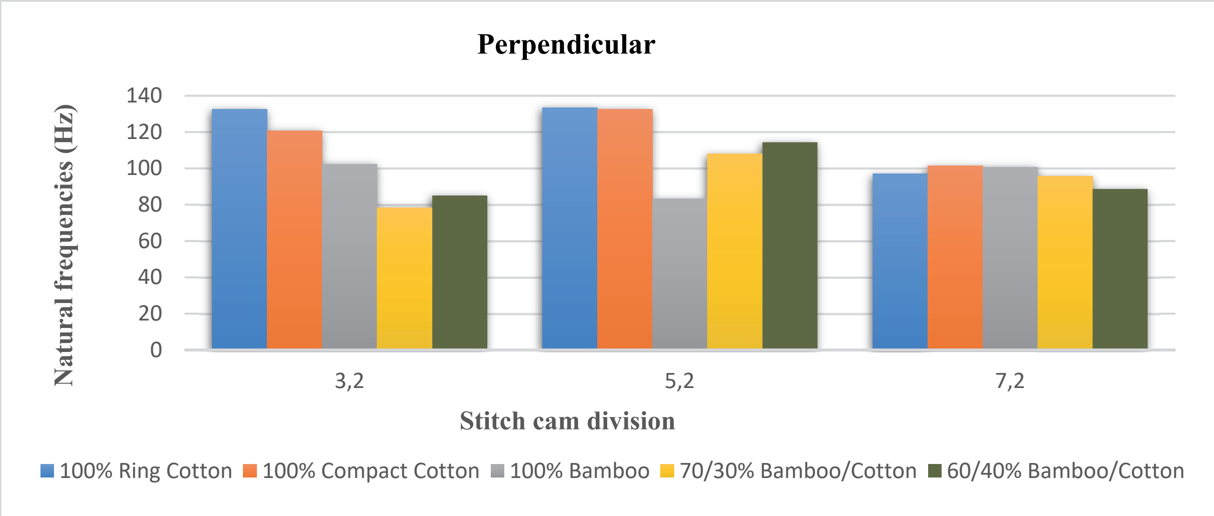


Figure 6. Natural frequencies of knits made of different yarns

The 100% bamboo knitted fabrics and the two variants of the bamboo/cotton blend had natural frequency values that were about 25% lower than those of the 100% cotton knitted fabrics. It can be concluded that the raw materials used for knitting play an important role, which requires further investigation.

5. CONCLUSIONS

The analysis of the test data on the recorded natural frequencies showed that this group of knitted fabrics has a low frequency level (20-180 Hz) compared to other groups of knitted fabrics investigated to date.

Given the different environments in which vibrations can occur, it is possible to find uses for these knitted fabrics other than the standardised ones on the market. For example, a knitted fabric with a lower thickness combined with good stretchability and suitable functionalization (antimicrobial, antibacterial treatment) combined with high wearing comfort can be a suitable protective material for certain medical applications, e.g. in dentistry.

Vibrations that affect the human body can be divided into three categories [23]:
- low frequency: 8 and 16 Hz (local); 1 and 4 Hz (general);
- medium frequency: 31.5 and 63 Hz (local); 8 and 16 Hz (general);
- high frequency: 125, 250, 500 and 1000 Hz (local); 31.5 and 63 Hz (general);

The strongest effects occur at frequencies close to the natural vibrations of the human body (6 - 9 Hz). Commercially available anti-vibration gloves are mainly a solution to reduce vibrations at high frequencies, as they are unable to provide significant reduction at frequencies below 150 Hz [23, 24].

The known natural frequency values of the knitted materials can serve for the design and control of the final application of these. If the natural frequency of the knitted material is lower than that of the vibrating object or the environment, vibration transmission will occur and the material can be used for massage purposes, for example. On the other hand, if the material has a higher natural frequency than the external vibrating system, this material can be used as an isolator against the vibrations.

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EFFECT OF MELT FLOW RATE ON MORPHOLOGICAL AND CHEMICAL CHARACTERISTICS OF POLYLACTIDE BASED SOLUTION CASTING AND NANOFIBROUS FILMS

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Abstract. *In this study, morphological and chemical characteristics of PLA based films produced by solution casting and electrospinning were investigated. PLAs at a concentration of 10% (wv^{-1}) were dissolved in dichloromethane (DCM)/ dimethyl sulfoxide (DMSO) at a weight ratio of 75/25% (vv^{-1}) to prepare the polymer solutions. These solvents were chosen as a good solvent and a non-solvent, respectively, for triggering pore formation in the structure. Three different PLA grades, i.e., 4032, 6202 and 6252, were used for determining the effect of melt flow rate (MFR) on the morphological, i.e., pore formation and nanofiber structure, and chemical characteristic of the solution casting and nanofibrous films. Morphological analysis has been performed using Tescan Vega3 scanning electron microscope (SEM). To evaluate the residual solvents in the structure, Fourier transform infrared (FTIR)-ATR Spectrometer was utilized. It was observed that even if all produced solution-casted films had porous structures, the morphological structure was found to be dependent on polymer solution viscosities, which varied according to MFR values of PLA. The polymer solution PLA6252 produced thicker fibers than its counterparts, possibly due to the low molecular weight enabling crystallization during fiber formation. FTIR analysis indicated that some residual solvents remained in the structure of electrospun nanofibrous mats in particular.*

Keywords: *Polylactide, solution-casting, electrospinning, melt flow rate, phase separation*

1. INTRODUCTION

Polylactide (PLA) has increasingly drawn much interest in the development of sustainable materials since it is derived from natural resources, and hence is biodegradable, and a good candidate for replacing petroleum-based polymers [1]. PLA and PLA blends can be used in several engineering applications due to its good thermal, physical, and mechanical properties. Accordingly, PLA-based porous materials have been used widely in tissue engineering [2], drug delivery [3], pH indicator [4], filtration [5], separation [6], sensor application [7], and food packaging [8].

There are various methods to prepare porous materials for wide engineering applications [9]. In this study, the pore formation in PLA-based membranes produced by solution casting and electrospinning was explored. Dichloromethane (DCM) and dimethyl sulfoxide (DMSO) were used as a good solvent and a non-solvent, respectively, for inducing phase separation, hence pore formation. Various PLA grades were used for determining the effect of melt flow rate (MFR) on the pore formation and morphological characteristic of the solution casting films and nanofibrous mats. To evaluate the residual solvents in the produced solution casting films and nanofibrous mats, Fourier transform infrared (FTIR)-ATR Spectrometer was utilized.

2. EXPERIMENTAL PART

2.1. Materials

PLA grades were supplied from NatureWorks LLC (USA) (Table 1). Dichloromethane (DCM, 99% purity, ISOLAB) and dimethyl sulfoxide (DMSO, 99% purity, ISOLAB) were used as solvents (Table 2).

2.2. Preparation and characterization of polymer solutions

The polymer solution parameters were given in Table 3. The polymer solutions were prepared by dissolving PLA (10% wv-1) in DCM/DMSO blend for 3.5 hours at 30°C using a magnetic stirrer. After magnetic stirring, viscosity of the polymer solutions was measured using Brookfield DV-E digital viscometer with R2 spindle at 100 rpm.

2.3. Preparation and characterization of solution casting and electrospun films

To produce solution casting films, the polymer solutions poured into glass petri dishes and dried under fume hood at room temperature for 3 days followed by vacuum drying at 85°C for 3 days. Then, the dried films were removed from dishes and ground using a coffee grinder. Powders were further vacuum dried at 85°C for 3 days. The produced powders were used in chemical analysis.

The prepared polymer solutions were also used in the electrospinning method to produce nanofibrous mats. An Inovenso Nanospinner24 electrospinning device was utilized. The feed rate, voltage, and tip-to-collector distance were 1.3 ml/h, 20 kV, and 13 cm, respectively.

Table 1
Properties of the PLA polymers

Grade	D-content (mol %)	Melt flow rate (MFR) g/10min (210ºC)
PLA 4032 (HPLA)	1.4	7-10
PLA 6202 (MPLA)	2.0	15-30
PLA 6252 (LPLA)	1.4	70-85

Table 2
Properties of the solvents

Solvent	Boiling Point (°C)	Dielectric constant (ε)
DCM	40	8.93
DMSO	189	46.7

Table 3
The parameters of polymer solutions

PLA grades	DCM/DMSO ratio (%)
HPLA	75/25 vv^{-1}
MPLA	
LPLA	

2.4. Methods

The morphology of solution casting films and electrospun mats were analyzed using Tescan Vega3 scanning electron microscope (SEM). Before imaging, samples were coated with gold (Au)/palladium (Pd) for 2 min. The diameters of nanofibers were measured using ImageJ software. 100 measurements were taken on each sample, and average fiber diameter were calculated.

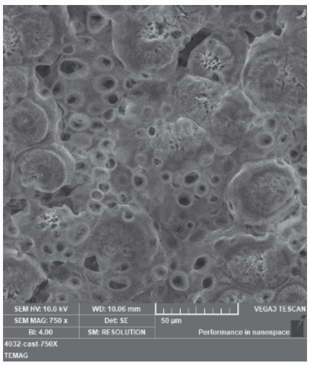
The chemical structure of mats and solution casting films was evaluated using Perkin Elmer Spectrum 65 Fourier transform infrared (FTIR)-ATR Spectrometer. The spectra within wavelength range of 500–4000 cm^{-1} were recorded with a resolution of 4 cm^{-1}.

3. RESULTS AND DISCUSSION

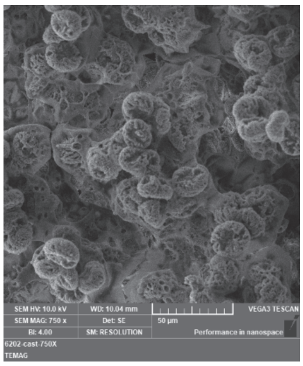
3.1. Morphological analysis

The SEM images of surface and cross-section of solution-casted films were given in Figures 1 and 2, respectively. It was observed that each film showed a porous structure related with the solubility of PLA polymer in the used solvents. PLA is insoluble in DMSO but soluble in DCM [10]. Thus, the mechanism of PLA porous membrane pore formation is associated with phase separation induced by non-solvent. When non-solvent is added to a polymer solution, the system's Gibbs free energy rises [11] and some DCM evaporates, forming a polymer concentration gradient that causes phase separation. As per the earlier study [9], the formation of an interpenetrating network structure was observed upon liquid–liquid phase separation. This network comprises two phases: and a polymer-rich phase that contains the polymer and some good solvent, and a polymer-poor phase that held the remaining solvent and the non-solvent. In the early stage, a co-continuous structure is developed; then the coarsening effect results in yielding the spherical particles. Phase separation remains until the two phases achieve a stable state with the lowest free energy.

In this study, even if all produced solution-casted films had porous structures, the morphology was different for each film, which could be related to polymer solution viscosities (Table 4) changing according to the MFR values (Table 1) of PLA polymers. Typically, a film with a higher viscosity encourages a larger pore size, as demonstrated by the HPLA film with the lowest MFR value. In addition, it was observed that HPLA (MFR: 7-10 g/10min) generated spherical pores, whereas LPLA (MFR: 70-85 g/10min) generated channels, in the solution-casted film. It was also observed on the polymer solutions that were poured into glass petri dishes as given in Figure 3. On the polymer solution, containing HPLA, a honeycomb-like shape formed (Figure 3a) immediately after pouring it into the petri dish, whereas a co-continuous shape (Figure 3b) formed on the polymer solution, containing LPLA.



(a)



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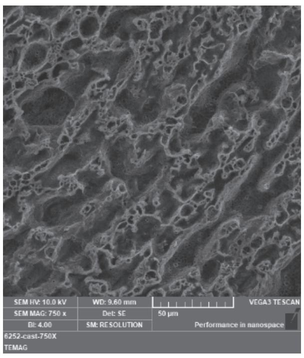
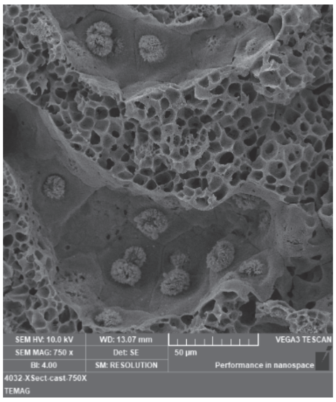
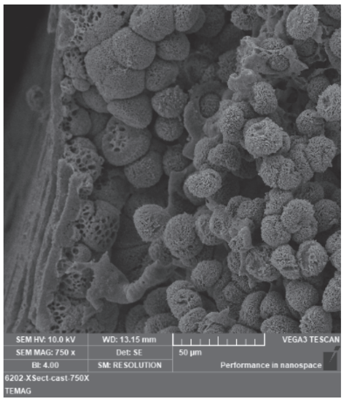


(c)

Figure 1. SEM images of solution casting films' surfaces, (a) HPLA; (b) MPLA; (c) LPLA.



(a)



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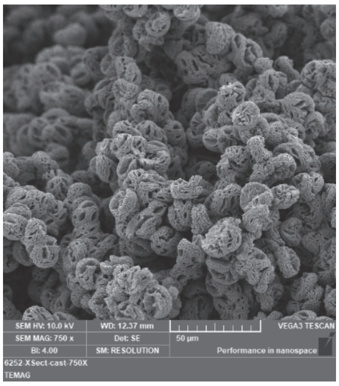
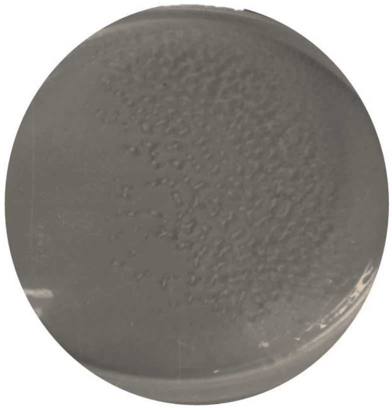


(c)

Figure 2. SEM images of solution casting films’ cross-sections, (a) HPLA; (b) MPLA; (c) LPLA.

(a)



(b)

Figure 3. Photographs taken right after polymer solutions were poured into petri dishes; (a) HPLA; (b) LPLA.

Table 4
Viscosity values of the polymer solutions

Polymer solution	Viscosity (cP)
HPLA	145.0
MPLA	88.8
LPLA	69.0

SEM images of nanofibrous mats were given in Figure 4 (a–c). It was observed that bead-free PLA fibrous mats were successfully produced. The mean fiber diameters were measured as 1349±200 nm, 938±150 nm and 1900±500 nm generated from the polymer solutions of HPLA, MPLA and LPLA, respectively. In general, a polymer solution having a low viscosity yields nanofibers with a low mean fiber diameter. However, it was obvious that the polymer solution of LPLA yielded thicker fibers compared to its counterparts. This could be due to the fact that LPLA has a high MFR value, indicating that it has a low molecular weight. Having a low molecular weight may ease the crystallizability of LPLA during fiber formation, and resulted in yielding thicker fibers compared to MPLA and HPLA.

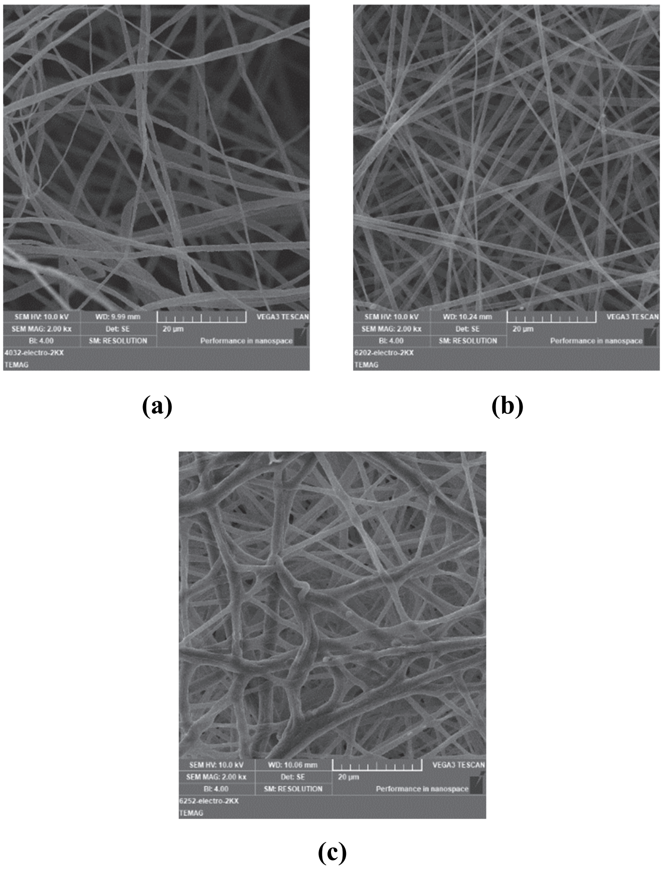


Figure 4. SEM images of electrospun nanofibrous mats, (a) HPLA; (b) MPLA; (c) LPLA.

3.2. Chemical analysis

FTIR spectra of the solution casting films and nanofibrous mats were given in Figure. The peaks approximately at 3000 cm^{-1} correspond to the C–H stretching in PLA. It was observed that the relative intensities of the peaks at this wavelength amplified for all nanofibrous samples. The presence of residual solvent could be responsible for these structural changes in the PLA peaks since C-H stretching at 3000 cm^{-1} also exists in DMSO and DCM solvents [12]. It was observed that, especially the electrospun nanofibrous mats of HPLA and MPLA showed intense FTIR peaks compared to neat PLA granule. This indicates that there may be some solvent remained in the system. On the other hand, due to a long drying process, FTIR spectra of solution casting films were quite similar to neat PLA granule. Since residual solvents in the structure of nanofibrous mats could affect the final mechanical properties, it would be better to dry the produced nanofibrous mats in a vacuum oven before the testing stage.

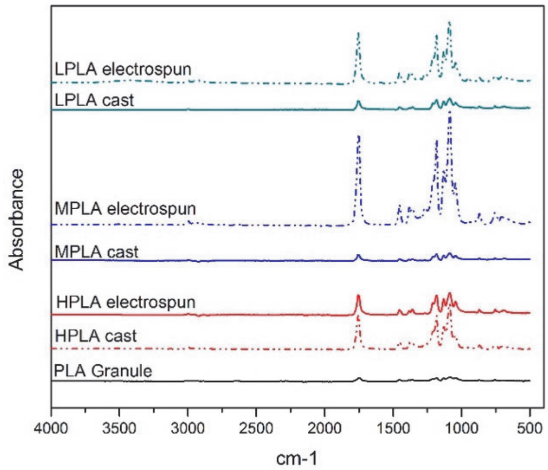


Figure 5. FTIR spectra of solution casting films and nanofibrous mats

4. CONCLUSIONS

In this research, PLA grades having different melt flow rate (MFR) were used for determining its effect on the morphological, i.e., pore formation and nanofiber structure, and chemical characteristic of the solution casting films and nanofibrous mats. It was observed that even if all produced solution-casted films had porous structures, the morphological structure depended on viscosities of the polymer solution changing according to the MFR values of PLA polymers. In addition, the polymer solution of LPLA yielded thicker fibers compared to its counterparts which could be due to a low molecular weight could facilitate the crystallization of LPLA during fiber formation, and resulted in yielding thicker fibers compared to MPLA and HPLA. Based on the FTIR spectra, it was concluded that some residual solvents remained in the structure of especially electrospun nanofibrous mats.

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SUSTAINABLE CONSUMER BEHAVIOUR AND THE FASHION FOOTPRINT OF CHILDREN'S CLOTHING: A ROLE FOR MOTHERS

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Abstract. *The concept of sustainability assumes a sustainable society based on corporate sustainability, but also on socially responsible consumers, and overall, the challenges are linked to both responsible production and responsible consumption. Nowadays, in the age of fast fashion, responsible production from the fashion brands' point of view means doing more with less resources and implementing a circular economy. As for responsible consumption through demand reduction, this depends above all on the awareness and responsibility of individual consumers for the environmental impact of their habits and actions. Therefore, a sustainable commitment for both sides should include the following: strategies to minimise environmental impact through quality clothing and eco-label certification to prove it (from the manufacturers' point of view) and buying quality clothing through sustainable purchasing choices to reduce the fashion footprint (from the consumers' point of view).More than ever, consumers are responsible for reducing their own fashion footprint and their awareness of the life cycle of fashion products must be linked to the 5Rs (zero-waste movement). When it comes to children's clothing, the aspects of reducing consumption and/or extending the life cycle of products take on a new meaning for mothers who are faced with the challenge of providing their children with garments that correspond to their physical development during the different stages of growth. This paper presents some results of a survey that targeted mothers with children aged between newborn and 18 years. The aim was to obtain responses on relevant elements outlining the profile of mothers as responsible consumers in terms of fashion footprint: general behaviour when buying children's clothes, ranking of factors influencing the purchase decision (including eco-labels) and finally, actions taken in relation to the 5 Rs.*

Keywords: *sustainability, responsible consumers, children's clothes, 5Rs, fashion footprint.*

1. INTRODUCTION

The concept of sustainability, defined as *the ability to exist and develop without reducing natural resources for the future*, involves a sustainable society based on corporate sustainability but also on socially responsible consumers [1]. Considering the links between the garment industry and its consumers, it can be identified two out of three sustainability pillars (planet-people-profit), as follows: *planet*, with the meaning of *the environmental protection* depending on the textile supply chain and *profit*, with the meaning of the *economic development* depending on the dynamic balance between both, the human and natural resources. In this context, the challenges of sustainability are related to responsible production and responsible consumption.

Nowadays, in the age of fast fashion, responsible production from the perspective of fashion brands should mean doing more with less resources and adopting a circular economy to reduce waste, create an efficient supply chain and reuse resources, but also with an awareness of ethical sourcing [1,2,3]. In a 2021 report by the World Economic Forum, the fashion industry and its supply chain are identified as the world's third largest polluter (after the food industry and construction), the world's second largest consumer of water and responsible for about 10% of global carbon emissions. Therefore, the question arises whether fast fashion companies, which produce huge quantities of cheap clothing, are really committed to sustainable fashion practices. In this context, “greenwashing” is emerging and needs to be combated, e.g., by developing online tools that allow customers to check the sustainability ratings of fashion companies [4, 5, 6]. The impact of sustainable policies of garment manufacturers and fashion brands can be constructive for business not only as revenue (profit), but also as a strategy to attract customers who share similar principles. For fashion brands, a sustainable strategic approach would be to have their products certified to standards by an impartial third party and to offer consumers eco-labels for their clothing in addition to the usual brand, informative and descriptive labels. Eco-labels are a voluntary method of certifying the environmental performance of products and services practised worldwide. By claiming that their clothes are environmentally friendly or „green", fashion brands aim to gain the trust of consumers [7, 8].

As for responsible consumption through demand reduction, this depends above all on the awareness and responsibility of individual consumers for the environmental impact of their habits and actions.

Therefore, a sustainable commitment from both sides should include the following: strategies to minimise environmental impact through quality clothing and eco-label certification to prove it (from the manufacturers' point of view) and buying quality clothing through sustainable purchasing choices to reduce the fashion footprint (from the consumers' point of view) [9,10,11].

The fashion footprint is the amount of greenhouse gases emitted by all fashion activities, including designing, manufacturing, shipping, buying, wearing, cleaning, and disposing of clothes [12]. Considering the global need to reduce the fashion footprint, irrespective of the type of consumer, everyone who buys clothes can be motivated and committed to the challenge of becoming responsible consumers by following at least the 5 Rs for fashion [12,13,14].

Consumer education and awareness of the textile value chain and sustainability in the life cycle of fashion products are linked to the 3Rs initiative (for waste reduction) and especially the 5Rs movement (for zero waste). The 3Rs Initiative was launched in 2004 (as a G8 initiative) with the aim of promoting the "3Rs" (Reduce, Reuse and Recycle) to change global consumption and production patterns towards a global society with a healthy approach to the life cycle of materials [15,16]. In 2013, the 3 Rs became the 5 Rs of sustainability, because it can no longer be about "waste reduction", but about "zero waste", as recycling capacities on a global scale are low, and huge amounts of waste end up in landfills worldwide [15,16, 17].

In children's clothing, the aspects of reducing consumption and/or extending the life cycle of products take on a new meaning for mothers who are faced with the challenge of outfitting their children with a variety of garments that correspond to specific physical development at different stages of growth [18, 19, 20]. For baby clothes, the commitment to compliant and sustainable clothing is particularly challenging: fashion brands apply quality assurance strategies and demonstrate their commitment to environmentally friendly measures (including eco-labels) in different ways to gain the trust of the customers who buy the final product (mothers). The "direct beneficiaries" (babies) are clothed with what the mothers buy, who, depending on their means/education/sustainable consumption patterns, appreciate the textile companies' efforts to reach the niche market with suitable baby clothes, not only from an aesthetic point of view. Considering that success in the market generally requires satisfied and loyal customers, the question arises whether the efforts made in the textile value chain are complemented by the market success of the garment when the end customer (the buyer) is not the direct beneficiary (the wearer) [19]. Therefore, it is more challenging for mothers to engage in sustainability, as they must consider certain aspects when buying clothes for their children, especially for babies [14, 19].

This paper presents some results of a survey that targeted mothers with children aged between newborn and 18 years. The aim was to obtain responses on relevant elements outlining the profile of mothers as responsible consumers in terms of fashion footprint: general behaviour when buying children's clothes, ranking of factors influencing the purchase decision (including eco-labels) and finally, actions taken in relation to the 5 Rs.

2. CHILDREN'S CLOTHING: SUSTAINABLE CONSUMER AND THE FASHION FOOTPRINT

When it comes to children's clothing and their different growth phases, what remains essentially the same is that children go through various changes in their gradual development that take place at a certain age or age range, from new-born to school age [18, 19, 20]. The goal of reducing the fashion footprint of children's clothing is therefore more challenging than for adult clothing.

A special category of children's clothing is the one designed for babies, as they cannot yet express their preferences in terms of the clothes they wear. The age range of babies is from birth to 3 years and includes new-borns (0-3 months), infants (3 - 12 months) and toddlers (1 - 3 years). All children, but especially babies, need comfortable clothing made with a combination of materials that provide them with complex functionality. At the same time, it is important to ensure that wearing these clothes does not expose the little ones' bodies to the harmful effects of some potential chemicals used in manufacturing processes specific to the textile value chain. A particular aspect of the approach to the environmental footprint of baby and children's clothing is that the end users are the babies, but the mothers as consumers make the purchasing decision for children's clothing that is appropriate in every respect and can behave responsibly from a sustainability point of view (e.g. buying eco-labelled clothing and adopting the principles of 5Rs movement).

2.1. Sustainable consumer vs. Ecolabelling

Eco-labels (owned or managed by government agencies, non-profit environmental organisations or private companies) identify garments that are proven more environmentally friendly. They are placed on product packaging so that consumers can easily identify which products meet certain environmental criteria and are “eco-friendly". Eco-labels can be single or multi-level, focus on the entire life cycle of a garment (production - use - care - disposal) and take into account different environmental aspects of the fashion footprint (e.g. raw material sourcing, energy consumption, use of chemicals, recycling, etc.) [10, 11].

An analysis of various Lupilu® brand baby-clothing products identified 13 eco-labels on the product packaging, all of which are intended to inspire confidence in the company's sustainable policies (Figure 1).

Figure 1. Eco-labels available on baby clothes –*Lupilu*® brand

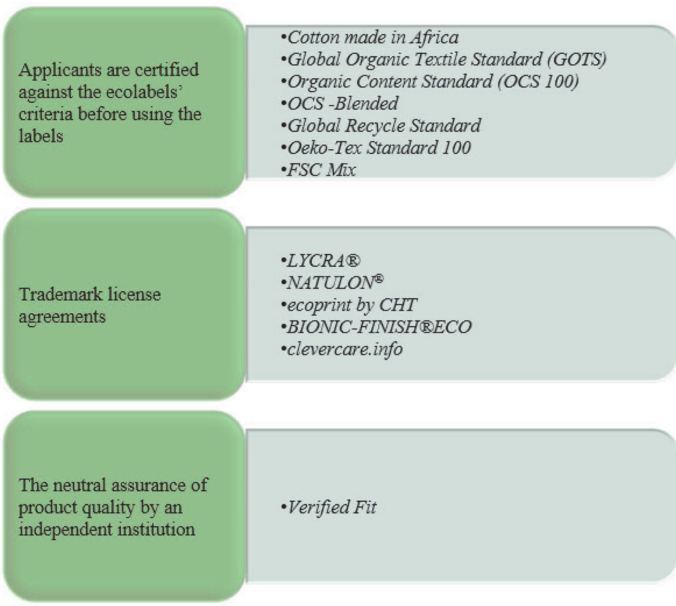


Figure 2. Relevant information about the eco-labels used by *Lupilu*® for baby clothes [21, 23-33]

All 13 labels are provided to potential buyers (in this case the mothers buying the children's clothes) as proof of responsible manufacturers, and some details are shown in Figure 2 [19, 21,22].

Customers need trustworthy and accessible information for eco-labels and in this context the Ecolabel Index should be mentioned. This is a freely accessible platform that collects data on eco-labels worldwide and has been providing information, comparison, monitoring and transparency in ecolabel evaluation since 2007 so that buyers and sellers can use them more effectively [21].

2.2. Sustainable consumer vs. the 5Rs

Today, more than ever, consumers are responsible for reducing their own fashion footprint [34]. Therefore, their awareness of the life cycle of fashion products needs to be linked not to the 3RS but to the 5Rs in order to connect to the Zero Waste movement [15,17].

The 3Rs initiative, which stands for Reduce, Reuse and Recycle (for waste prevention/reduction), has been transformed into the 5Rs movement, which stands for Refuse, Reduce, Reuse, Recycle and Rethink / Repurpose (for zero waste). In this context, the pressure on fashion brands is to act as sustainable corporations, i.e. according to the three pillars (environmental protection, social and economic development) is meant to lower their overall impact on the planet and people. Nevertheless, consumers have their own responsibility to reduce their fashion footprint. Therefore, considering the 5 Rs for fashion, they have an adapted meaning for the responsible consumers, as shown in Figure 3 [6,12].

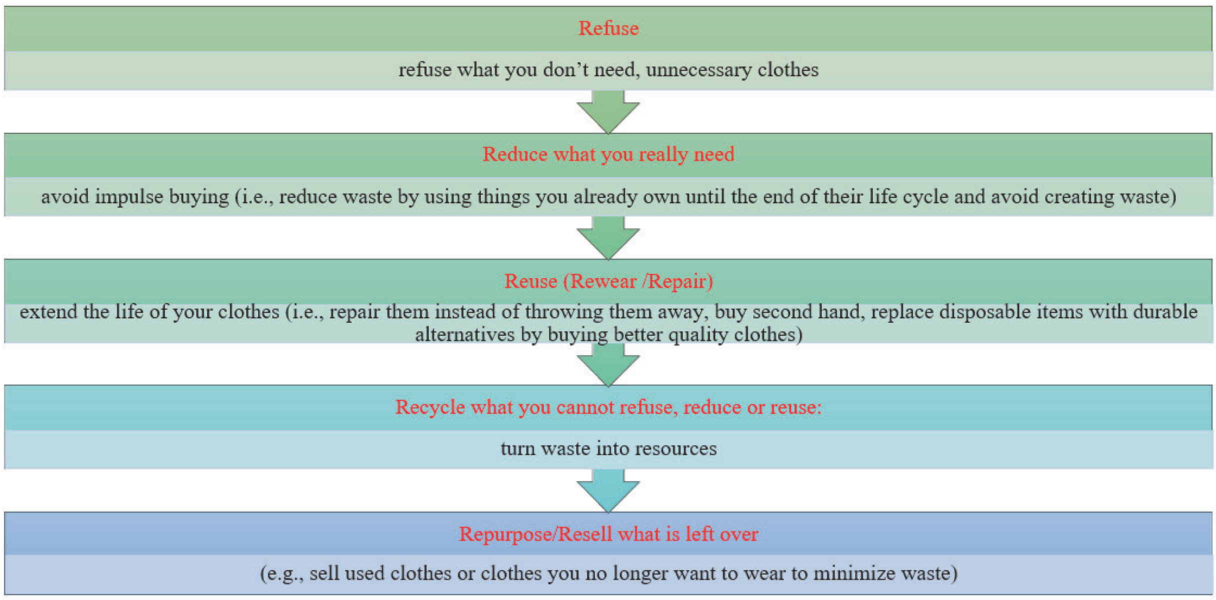


Figure 3. The 5 Rs for fashion

3. A CASE STUDY: INVESTIGATING MOTHERS' BEHAVIOUR AS RESPONSIBLE CONSUMERS TO REDUCE THE ENVIRONMENTAL FOOTPRINT OF CHILDREN'S CLOTHING

3.1 Regarding the environmental footprint of children's clothing

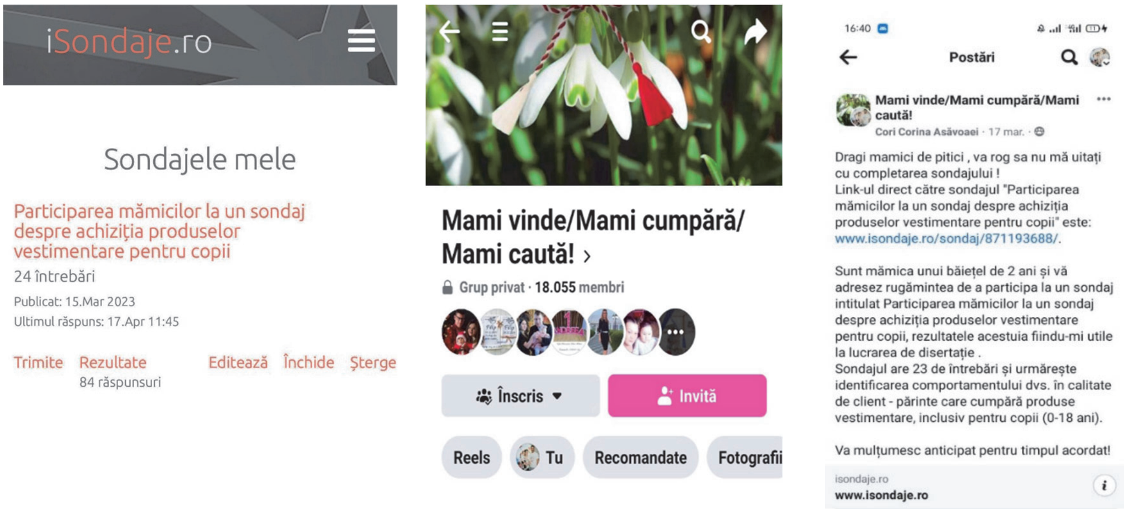
All companies that get certified to put an eco-label on their products sold in the consumer market have to bear high costs to maintain the level set by the standards. These costs are intended to provide some advantage over the competition represented by manufacturers who do not participate in strategies that certify the compliance of products from a sustainability perspective. So, what is advantageous for manufacturers should also be perceived as an advantage for consumers, but also for the environment, the economy and society, because eco-labels are certificates of conformity for products that have an impact on society as a whole.

In this context, it would be interesting to find out how mothers feel about the 5Rs movement, whether they understand its importance (in their need to become responsible consumers), assess the benefits of eco-

labels for the enviromental footprint of children's clothes and whether they are willing to accept higher costs for more expensive but environmentally friendly clothes.

3.2. Regarding the survey of mothers' behaviour as responsible shopper of children's clothing

Important details about the behavior of mothers when buying children's clothes were obtained from a questionnaire entitled "*Mothers' participation in a survey on the purchase of children's clothes*" (see Figure 4.a) [35]. The questionnaire was written in Romanian and contains a field with general information about the respondents and a group of 24 questions - 5 different types of questions (from questions with simple answer options to questions on a 4-point Likert scale) to ask respondents' opinions related to the selected topic. The survey link was distributed along with an invitation on the social media platform Facebook, to the target group: *Mum Sells / Mum Buys / Mum Searches, Advice, Diversification, Entertainment - Midgets and Mummies,* with a corresponding invitation, Figure 4b [19,35].



a) **b)**

Figure 4. Survey addressed to mothers (in Romanian): a) - Survey access window; b) - Survey on Facebook

4. RESULTS AND DISCUSSION

4.1. On the behaviour of mothers as responsible buyers of children's clothing

The survey was completed by 84 mothers with an average age of 36 years (21÷ 61). Below is a summary of the answers to the 24 questions.

Education and the connection with the textile field

- 75% of respondents have higher education (40.5% of mothers with a university degree, 25% with a master's degree and 9.5% with a doctorate) and 25% have a secondary school degree.
- 76.1% of the respondents live in urban areas and 23.8% in rural areas.
- 60.7% of mothers have nothing to do with the textile sector. The rest of the sample (39.3%) consists of mothers who are only involved in the fashion sector (15.5%), mothers with a degree in textiles (14.3%), mothers with a degree in textiles who work in this sector (7.1%) and mothers who work in the sector without having a specific degree (2.4%).

Children in the family

- 48.8% of mothers are from couples with one child; 45.2% are from couples with several children; 6% are single mothers with one or more children.
- In 63.1% of the respondents' families there is only one child under 18; in 29.8% of the families there are two children and only 7.1% of the families have more children under 18.
- The 169 children (100 girls and 69 boys) of the 84 respondents who participated in the survey are distributed by age as follows: 16 newborns (0-3 months); 16 infants (3 - 12 months); 36 toddlers (1 - 3 years); 33 preschoolers (3-6 years); 32 school children (6 -12 years); and 36 teenagers (12 -18 years).

Purchasing power and purchasing habits

- 78.6% of mothers reported having average purchasing power so that they can manage with the allocated budget when it comes to buying new clothes for the family. The extremes are: 13.1% of mothers reported having low purchasing power (they save to buy clothes and only when necessary) and 8.3% reported having high purchasing power (they do not save to buy clothes and can afford to buy them whenever they want, no matter what they buy).
- 88.1% of respondents usually buy their clothes according to their needs: 36.9% of respondents buy clothes several times per season; 26.2% of respondents buy clothes regardless of price/season/offers; 25% of respondents buy clothes about once per season. In contrast, 11.9% of respondents buy clothes very rarely: only when needed, not considering discount periods (7.1%) or only in times of discounts/offers, regardless of need (4.8%).
- Regarding the usual way of buying clothes for themselves or family members: they never buy clothes without analyzing the materials by reading the label: 67.9% of mothers fully agreed with this statement, 20.2% partially agreed and 11.9% disagreed.

The respondents' attitudes towards fashion trends are divided into three quite close areas: 39.3% know the fashion trends but do not follow them; 33.3% do not know the fashion trends; 27.4% know the fashion trends, follow them closely and try to dress the family members (including children) in fashion trends.

Respondents' attitude towards the most important factors in their decision to buy clothes

A ranking of six factors that mothers consider when buying clothes for family members and that influence their purchase decision shows that the quality of the materials from which the product is made, and the purchase price are in the first two places, with close share: 24% and respectively 22% of mothers. The quality of the manufacturing (the visual aspect of the assembly, the decorative stitching, embroideries) and the accessories (zips, buttons, etc.) are in third place (17% of mothers). The following three factors influencing the purchase decision have almost share: in the fourth, fifth and sixth place (13%/13%/12% of mothers) is the information on the product labels (inside, outside), the duration of product use and fashion trends (including for children's clothing).

Respondents' attitude towards the clothes ecolabelling

Regarding the relevance of the information that appears on the label of a clothing product - crucial for the purchase decision: 18.4% consider the price of the clothing as the most important information; 15% for information about all the materials used in the product and 13.15% for information about the care of the product. A particular aspect is that 34.4% concern the importance of information provided by ecological labels: 12.1% by the eco-label certifying the absence of effects of the products on consumer health and the environment, 11.3% by the label certifying the origin and traceability of the raw materials and 11% by a label certifying the testing of the products, from the raw materials to the garment and accessories, for substances harmful to the health of the wearer. Other information considered less important in clothing labelling concerns: 8.4% for information about the manufacturing company and its country, and 5.5% for information about the manufacturer's sustainability policy. The least important was stated information about the brand company (4.5%) and information about the year the collection was launched (0.8%).

On buying eco-labelled clothes even if they are more expensive but prove the manufacturer's compliance with sustainability guidelines: 66.6% of respondents appreciate the importance of eco-labelled clothes and buy them even if they are more expensive: 34% of mothers buy such clothes for the whole family, and 32.1% of mothers buy them only selectively for their children. The remaining 33.4% of mothers prefer to buy cheaper clothes for the whole family: half of them do not have a sufficient budget, although they are aware of the importance of the eco-label, and the other half are not interested in the sustainability issue.

4.2. On mothers' behaviour in relation to the 5Rs to reduce the environmental footprint of children's clothes

A ranking of the main reasons for which respondents most often buy children's clothes shows that in first place, with 28% of respondents, is replacing clothes that are too small, and in second place, with 21% of respondents, is replacing used clothes (*out of necessity*). The next reasons in the hierarchy: to enrich their growing children's wardrobe (19% of mothers), to enrich their children's wardrobe as part of discount promotions (16% of respondents) *as spare clothes* and finally 17% of mothers shop to replace their children's outdated clothes, i.e., *not out of necessity or replacement*. Figure 5 gives an overview of the opinions of the mothers who participated in the survey regarding their behaviour in relation to the 5RS.

Figure 5. The results of the survey on mothers' behaviour in implementing the 5Rs movement for fashion footprint

In summary, when discarding worn clothes, most of the respondents extend the useful life of those by offering them to friends and close relatives (90.5%) or donating them to disadvantaged people (91.7%). Also, mothers take worn clothes to used clothing collection establishments (64.3%) or reuse them through various transformations (59.5%) to be useful to other family members. Never throw worn clothes in the household waste bin (79.8%) or in the recycling bin (61.9%).

On the other hand, mothers hardly agreed with the statement that they would rather buy second-hand clothes for the family or the children. Regardless of whether the clothes are for the children or the adults in the family, 80.6% of the mothers surveyed disagreed with this option, 17.1% partially agreed and only 2.4% strongly agreed with this involvement in Reuse action of the 5Rs movement.

4. CONCLUSIONS

Gaining, maintaining, and increasing customer confidence in the quality of their products is an important aspect of business strategy for most manufacturers and fashion companies. Nevertheless, companies strive to provide their customers with comprehensive information to demonstrate their continuous efforts to meet the imposed requirements of the sustainability principles. These efforts come at a significant additional cost. It is therefore important that fashion consumers are aware of these impacts and use the information provided in their purchasing decisions.

This study investigated the purchasing behaviour of a specific category of consumers, namely mothers buying clothes for their children. Although only 84 mothers participated in the survey, they are responsible of the environmental footprint of children's clothes, buying clothes for 169 children. Depending on their habits, mothers decide at least for 133 children (new-borns, infants, toddlers, pre-schoolers, and schoolchildren), if we exclude teenagers, what clothes and when they buy them for the children. Finally, mothers decide what to do with the worn clothes that the 169 children can no longer use for various reasons.

One of the objectives of this study was to identify the factors that influence the purchasing decisions, including the importance of the information provided on different types of labels. As far as buying habits are concerned, the most important findings are: 88.1% of the respondents usually buy their clothes according to their needs, 67.9% of the mothers never buy clothes without analysing the materials by reading the label and 39.3% know the fashion trends but do not follow them. Of the ten possible information on a clothing label that determine the purchase decision, 34.4% goes to the information provided by the ecological labels. Finally, 66.6% of respondents appreciate the importance of eco-labelled clothes and buy them even if they are more expensive (32.1% only for their children and 34.5% for the whole family).

Another objective was to find out to what extent these consumers pay attention to sustainability measures at the end of the products' useful life. Positive aspects are found in the behaviour of majority of mothers who are responsible for buying/disposing of clothes for 169 children, considering their views on overall aspects of the 5Rs movement. However, the lowest involvement is in the Repair activity (59.5%) which involves refashioning old/used clothes in different ways and may require skills and creativity. Regardless of whether the clothes are for the children or the adults in the family, 80.6% of the mothers interviewed rejected the possibility of buying second-hand clothes for the family or the children.

This study shows that mothers as consumers, but also as buyers of children's clothing, need more awareness and attention to sustainability measures at the end of the products' useful life. Their willingness to participate in reducing the environmental footprint of their children's clothing must therefore be transformed into a need that is fundamental to their future behaviour as responsible consumers, no matter what.

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EFFECT OF MANUFACTURING TECHNOLOGY ON THE PROPERTIES OF RECYCLED NONWOVENS AND COMPOSITES MADE THEREWITH

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Abstract. *To reduce the environmental impact, the nonwoven waste can be recycled within the original manufacturing process or sold to other industries to return to the production cycle of other products in a circular economy. In this study, the nonwoven waste consisting of 50% hemp and 50% recycled polypropylene was defibrated and the obtained recycled fibres were converted into new nonwovens using two different technologies. One technology consisted of opening and blending of 100% recycled fibres, aerodynamic web formation, and needle punching. The second technology consisted of opening and blending of 75% recycled fibres and 25% bicomponent fibres, aerodynamic web formation, and thermal bonding. On the first technology, the recycled fibres were obtained using a cutting machine and an opener, while on the second technology a shredder and a fine granulator were used for this purpose. The nonwoven fabrics produced with the two technologies were evaluated for their physical and mechanical properties. The study has shown that the thermal bonded nonwoven fabric had higher bulkiness, higher mass and thickness uniformity, and higher tensile strength in comparison with the needle punched nonwoven fabric. Thermoformed composite materials were obtained from each type of nonwoven fabric and characterized in terms of physical and mechanical properties. Composite materials manufactured from thermal-bonded nonwovens showed a higher tensile strength and a lower flexural strength than the composite materials manufactured from needle-punched nonwovens.*

Keywords: *recycled nonwovens, needle punching, thermal bonding, composite material, hemp reinforcement.*

1. INTRODUCTION

In a circular economy, waste from the manufacturing process or end-of-life products are transformed into secondary raw materials that return to the production cycle of new products, thus being kept in the economy as long as possible, in a closed circuit [1-3]. The circular economy is a model of production and consumption that aims to maximize resource utilization while minimizing waste [4]. Circular economy principles encourage the efficient use of resources by keeping materials in use for as long as possible. This reduces the need for virgin resources, mitigates resource depletion, and can result in cost savings for companies through reduced material and disposal costs [5, 6]. To minimize waste generation, products are designed to be easily repaired, refurbished, or recycled. Design for recycling and design from recycling are both eco-design strategies that enable companies to create more environmentally friendly products and reduce their environmental impact [7, 8]. By reducing resource extraction and waste generation, a circular economy helps mitigate environmental issues such as habitat loss, air and water pollution, and greenhouse gas emissions. Furthermore, the use of recycled materials significantly reduces the carbon footprint associated with resource extraction, production, and transportation [9]. In contrast to a linear economy, the circular economy represents a shift towards a more sustainable and responsible approach to resource management, production, and consumption.

In the manufacturing process of 3D thermoformed composites for furniture applications results aproximately 20% nonwoven waste [10]. This waste can be recycled by reworking its fibres to obtain new nonwovens for composite material manufacturing within the original production process or can be sold to other industries.

The purpose of this research was to study the effect of manufacturing technology on the properties of nonwovens prepared from recycled fibres and composite materials made therewith. The recycled fibres (a blend of 50% hemp and 50% recycled polypropylene) were obtained by defibration of nonwoven waste resulted from the manufacturing process of 3D thermoformed composites at Taparo Company. Two different technologies were used to convert the recycled fibres into new nonwovens. One technology consisted of nonwoven waste cutting and opening, blending and opening of 100% recycled fibres, aerodynamic web formation, and needle punching. The second technology consisted of nonwoven waste shredding, opening and blending of 75% recycled fibres and 25% bicomponent fibres, aerodynamic web formation, and thermal bonding. The obtained nonwoven fabrics and the composites made therewith were evaluated for their physical and mechanical properties.

2. MATERIALS AND METHODS

2.1. Fibre characteristics

The nonwoven waste was supplied by Taparo Company (Romania) and resulted from the cutting stage of nonwoven stack according to the pattern shape in the process of 3D thermoformed composite manufacturing. The nonwoven scraps contained 50% hemp fibres characterised by 15.8 tex linear density, 38.9 cN/tex tenacity, and 60 mm cutting length and 50% recycled polypropylene with the following characteristics: linear density – 9.9 dtex, tenacity – 25.2 cN/tex, elongation at break – 142.9%, and average length – 82.2 mm. For fibre recovery, the nonwoven waste was subjected to defibration which resulted in fibre shortening and, in the case of hemp fibres, an increase in fibre fineness due to the splitting of technical fibres into elementary fibres [10].

Polyethylene/Polypropylene bicomponent fibres used in the experiments were supplied by FiberVisions Company (Denmark). The characteristics of bicomponent fibres were as follows: linear density – 2.2 dtex, tenacity – 3.2 cN/dtex, elongation at break – 120%, length – 6 mm, polyethylene melting point – 130 ^{0}C, and polypropylene melting point – 162 ^{0}C.

2.2. Nonwoven manufacturing

Two manufacturing technologies were used to convert the nonwoven waste into new nonwovens made from recycled fibres.

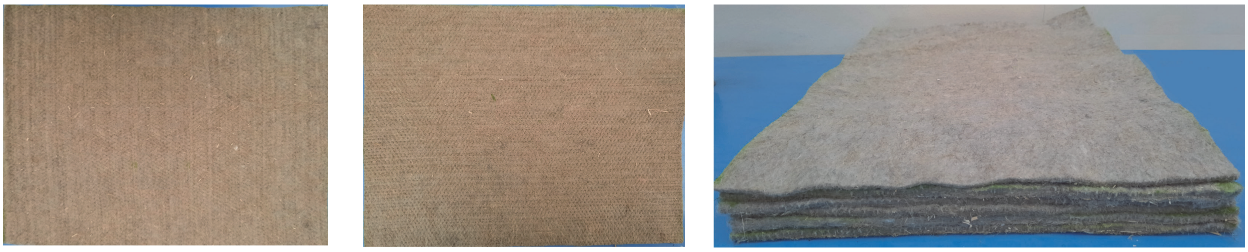
The technological line used to obtain needle-punched nonwoven fabric (Taparo Company, Romania) included a cutting machine (60 mm cut length) and a waste opener for nonwoven waste defibration and the following machinery for nonwoven manufacturing: a bale opener, an opener, a feeding chute, an opener, a perforated drum for web formation, two needle punching machines and a rolling device. Needle-punched nonwoven fabric made from 100% recycled fibres (50% hemp and 50% recycled polypropylene) was obtained on this technological line.

The technological line used to obtain thermobonded nonwoven fabric (Advance Nonwoven, Denmark) included a shredder (hammermill 20 mm) and a fine granulator (8 mm) for nonwoven waste defibration, and bale openers, CAFT web former (patented Carding Air-laid Fusion Technology), a double-belted oven and a rolling device for nonwoven manufacturing [11]. On this technological line, thermobonded nonwoven fabric made from 25% bicomponent fibres and 75% recycled fibres was produced. In the thermobonded nonwoven fabric, the composition consisted of 37.5% hemp fibres and 62.5% polymeric fibres.

2.3. Composite manufacturing

Thermoforming was carried out on a thermal press equipped with two plates that can be electrically heated up to 250 ^{0}C. The thermal press is equipped on the lower plate with a mold measuring 40 cm in length, 30 cm in width, and 20 cm in height. A water-cooling system is connected to both plates to reduce the solidification time of matrix.

To make the composite material from needle-punched nonwoven fabric, 6 pieces of nonwoven fabric were cut in accordance to thermopress mold dimensions and overlapped. Since the needle-punched nonwoven fabric has different tensile strengths in the machine direction and transverse machine direction, the samples were cut both longitudinally and transversely, and their overlapping was done alternately to obtain uniform properties (Figure 1). In the case of thermobonded nonwoven fabric, four samples were overlapped in the mold in order to obtain plate composite material (Figure 2). Thermoforming was carried out at a temperature of 190 ^{0}C and a pressure of 0.735 MPa. The pressing time was 15 minutes and the cooling time 10 minutes.



a b c

Figure 1. Needle-punched nonwoven fabric cut in the machine direction (a) and transverse machine direction (b), along with a nonwoven stack (c)

a b

Figure 2. Thermobonded nonwoven stack (a) and composite material made therewith (b)

2.4. Testing of nonwoven fabrics

The determination of the thickness of recycled nonwoven fabrics was carried out according to the EN ISO 9073-2 standard. Mass per unit area was measured in accordance with the SR EN 29073-1 standard. Samples with an area of 50000 mm^2 (250 mm x 200 mm) were cut, conditioned and weighed on an electronic balance. Tensile tests were performed on an LBG testing machine (Italy) in accordance with the SR EN 29073 – 3 standard. The samples were cut to a length of 300 mm and a width of 50 mm. The distance between the clamps was 200 mm and the test speed was 100 mm/min. Tensile properties were measured in both the machine direction and the cross direction. Five measurements were done for each sample.

2.5. Testing of composite materials

Flexural and tensile tests were conducted on composite materials using an LBG testing machine (Italy). For the tensile tests, specimens with a length of 250 mm and a width of 25 mm were employed, as specified in the EN 326-1 standard. Tensile test parameters were established in accordance with the ISO 527-4 standard, with a crosshead speed of 2 mm/min and a 150 mm distance between clamps. The dimensions of the specimens for the 3-point flexural test were determined based on the specifications outlined in the ISO 14125 standard. The specimen width was 15 mm, and the length varied depending on the specimen thickness. During the flexural tests, a cross-head speed of 2 mm/min was applied. A total of five specimens were tested to evaluate the tensile and flexural properties of the manufactured composite materials.

3. RESULTS AND DISCUSSION

3.1. The properties of nonwoven fabrics

The physico-mechanical properties of recycled nonwoven fabrics are presented in Table 1. As can be seen in Table 1, the thermobonded nonwoven fabric exhibited a thickness that was 3.2 times greater than that of the needle-punched nonwoven fabric. This increased thickness in the thermobonded variant, coupled with its lower density, results in greater bulkiness, specifically indicating a larger volume of air trapped within its structure. This observation is noteworthy as it can potentially exert a significant impact on heat transfer during the thermoforming process.

The data in Table 1 highlight the better uniformity of the thermobonded nonwoven fabric in terms of thickness, mass per unit area, density, tensile strength and elongation at break when compared to needle-punched nonwoven fabric.

Table 1

Physico-mechanical properties of recycled nonwoven fabrics

Properties			Needle-punched nonwoven fabric	Thermobonded nonwoven fabric
Thickness		Average value, mm	6.07	19.3
		CV, %	11.11	2.4
Mass per unit area		Average value, g/m^2	573.61	1335.2
		CV, %	17.59	6.01
Density		Average value, kg/m^3	94.66	69.2
		CV, %	15.48	6.54
Tensile strength	Machine direction	Average value, MPa	0.071	0.331
		CV, %	28.96	13.104
	Transverse direction	Average value, MPa	0.037	0.404
		CV, %	9.75	7.06
Elongation at break	Machine direction	Average value, %	29.780	21.78
		CV, %	10.93	6.95
	Transverse direction	Average value, %	39.780	28.62
		CV, %	28.52	2.26

The thermobonded nonwoven fabric showed a tensile strength much higher in both directions than the tensile strength of needle-punched nonwoven fabric (4.6 times higher in machine direction and 10.9 times higher in transverse direction). The tensile strength of needle-punched nonwoven in the machine direction is almost 2 times higher than the tensile strength in the transverse direction. In contrast, in the thermobonded nonwoven, due to the different principle of formation and consolidation of the web, the tensile strength in the transverse direction is higher by 22% than the tensile strength in the longitudinal direction.

The elongation at break of thermobonded nonwoven fabric is lower than the elongation at break of needle-punched nonwoven fabric both in the machine direction and in the transverse direction.

3.2. The properties of composite materials

Table 2 shows the properties of composite materials made from recycled nonwoven fabrics.

Table 2

Properties of composite materials made from recycled nonwoven fabrics.

Properties		Needle-punched nonwoven fabric-based composite	Thermobonded nonwoven fabric-based composite
Thickness	Average value, mm	3.4	3.9
	CV, %	10.9	1.14
Tensile strength	Average value, MPa	20.8	23.67
	CV, %	21.4	6.21
Elongation at break	Average value, %	1.87	2.37
	CV, %	28.5	9.39
Flexural strength	Average value, MPa	47.3	42.88
	CV, %	14.55	11.34

The tensile strength of the thermobonded nonwoven fabric-based composite (TNC) is higher by 13.8% than the tensile strength of the needle-punched nonwoven fabric-based composite (NPNC) due to a better embedding of hemp reinforcing fibres as a result of a higher content of the polymeric matrix (62.5% vs. 50% in the needle-punched nonwoven fabric-based composite). Figure 3 presents the force-elongation curves of the two types of composite materials. The curve corresponding to thermobonded nonwoven fabric-based composite is characterized by a steeper slope which means that the composite exhibits a higher resistance to deformation for a given force, therefore a greater stiffness. The thermobonded nonwoven fabric-based composite exhibits a higher yield point and ultimate strength, indicating greater load-bearing capacity.

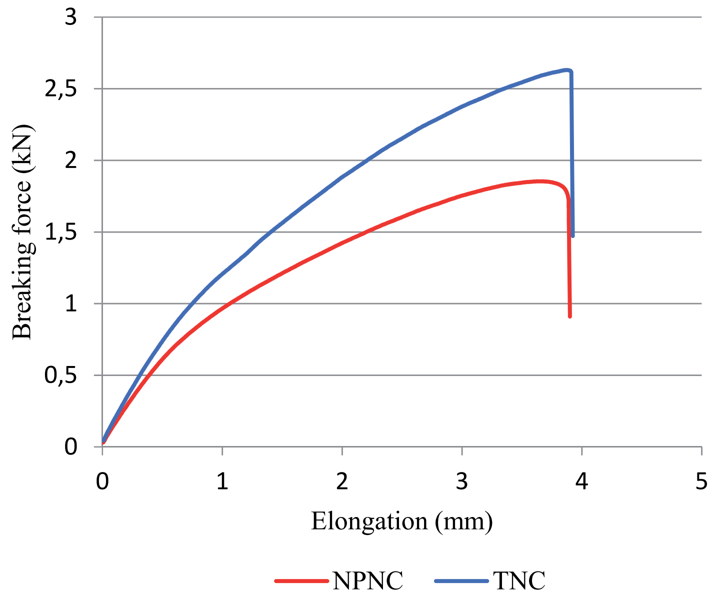


Figure 3. Force-elongation curve of composite materials

The elongation at break of the thermobonded nonwoven fabric-based composite is higher than the elongation at break of the needle-punched nonwoven-based composite due to an increased proportion of the polymeric matrix. Polypropylene (PP) is a thermoplastic polymer known for its ductility. When a higher percentage of PP is used in the composite, it imparts these properties to the entire material. Ductile materials can undergo significant deformation before breaking, leading to a higher elongation at break.

The data presented in Table 2 reveals that the flexural strength of the thermobonded nonwoven fabric-based composite is 9.3% lower than that of the needle-punched nonwoven-based composite. This difference can be attributed to the shorter length of the reinforcing hemp fibres resulting from the defibration of the nonwoven scraps. In the thermobonded nonwoven manufacturing process, the defibration of nonwoven waste was carried out using a shredder (hammermill 20 mm) and a fine granulator (8 mm), which entails a more aggressive treatment of the fibres, hence resulting in a reduced length of the reinforcing hemp fibres.

All the characteristics of the thermobonded nonwoven fabric-based composite showed lower coeffiecients of variation in comparison with the characteristics of the needle-punched nonwoven fabric-based composite. This means that the measurements for a characteristic had less variability when compared to the average of the data, so the characteristic was relatively uniform across the observations. The enhanced uniformity in the properties of the thermobonded nonwoven fabric-based composite can be attributed to the superior uniformity in the properties of the thermobonded nonwoven fabric when compared to the characteristics of the needle-punched nonwoven fabric. The high variability in the characteristics of the needle-punched nonwoven fabric may be attributed to the lack of a weighing pan in the bale opener, leading to fluctuating quantities of fibres being fed per unit of time.

4. CONCLUSIONS

Recycling is a fundamental component of the circular economy, where products and materials are reused, remanufactured, or recycled to minimize waste and maximize resource efficiency. Manufacturing waste recycling is vital for environmental protection, resource conservation, cost savings, and contributes to a more circular, sustainable and responsible approach to manufacturing.

In this paper, the influence of two distinct technologies of waste recycling and nonwoven production on the properties of recycled nonwovens and composites made therewith was investigated. The composition of the manufacturing nonwoven waste consisted of 50% hemp and 50% recycled polypropylene. Needle-punched nonwoven fabric was produced from 100% recycled fibres through the following steps: cutting nonwoven waste (60 mm) and opening, blending and opening of recycled fibres, aerodynamic web formation, and needle punching. In the second technology, thermobonded nonwoven fabric was produced from 75% recycled fibres and 25% bicomponent fibres through the following steps: shredding nonwoven waste (20 mm) and grinding (8 mm), opening and blending of recycled and bicomponent fibres, aerodynamic web formation, and thermal bonding. Nonwoven fabrics were employed in the production of composite materials through thermoforming.

Compared to the needle-punched nonwoven fabric, the thermobonded nonwoven fabric exhibited greater bulkiness, higher tensile strength in both the machine and transverse directions, and greater uniformity in all characteristics.

The thermobonded nonwoven fabric-based composite showed greater tensile strength and elongation at break, but lower flexural strength compared to the needle-punched nonwoven fabric-based composite material.

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TEXTILE FIBERS IN 3D PRINTING

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***Abstract**. Rapid prototyping, as the concept of 3D printing was first defined by Dr. Hiedo Kodama in 1980, and later in 1986 with Chuck Hull's first patent for stereo lithography, will open the door to an entire industry. Interest in new prototyping methods was evolved in the late 1980s with the development and patenting of new techniques such as Carl Deckard's selective laser synthesis (SLS) and Scott Crump's fused deposition modelling. Dr Adrian Bowyer and the open source RepRap project in 2005, as well as the public domain entry of many of the patents filed in the 1980s, have triggered exponential growth in the market and interest in developing new 3D printing machines and materials for use in prototyping. Becoming an accessible technology but also thanks to its standardization, since 2009 3D printing has turned into a real industry. The main advantages that have led to the widespread adoption of the technology are mainly related to the ease with which one can go from the initial idea to the final product in just a few hours with great design freedom, low labour, energy and raw material costs. Depending on the type of printing, different raw materials are used: traditional petroleum-based polymers, such as polypropylene (PP), polyvinyl chloride (PVC), and polyethylene (PE), polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), nylon, natural polymer and hydrogels. Various additives, plasticisers and fillers have been developed to optimise the print quality in order to improve the crystallisation, flowability, toughness properties and reduce the glass transition period and melting temperature of the polymer matrix used in 3D printing. Textile fibres play an important role in the category of fillers designed to improve both the physical-mechanical properties and the biodegradability of prints. Research on this topic is diverse and addresses different categories of natural and synthetic fibres found in continuous yarns or filaments, fibres and nanofibres used in blends in composites for 3D printing. Through this paper, we want to review the research carried out until now, in which textile fibers are used in 3d printing with the aim of identifying opportunities for further research and new directions.*

***Keywords:** prototyping, composites, 3D printing filament, thermoplastic.*

1. INTRODUCTION

Traditional object manufacturing involves removing material from a processed workpiece through various mechanical, thermal, or chemical methods until the desired product is obtained. Even in the case of injection molding, the creation of the mold is necessary to obtain the desired object, which entails costs associated with mold design and production, non-functional prototypes, rejected products, and significant consumption of raw materials. All these processes entail considerable efforts and costs, inevitably leading to an extended time for the launch of new products.

3D printing has undergone significant evolution in the last decade, likely due to the reduced quantity of raw materials used in the process. According to the scientific literature, the workflow for creating a 3D product is the same in all available technologies and consists of three basic steps: creating a 3D model through specialized software, printing, and then cutting [1], [2], [3]. Each stage has specific characteristics, creating the model requires skills in using CAD (Computer-Aided Design) software, which can be adapted to the characteristics of the printers used. The printers used and developed up to this point have somewhat similar technologies.

Up to the present, various rapid prototyping technologies have been developed, according with Z Spot Media including: a) FDM – Fused Deposition Modeling; b) SLA – Stereolithography; c) DLP – Digital

Light Processing; d) SLS – Selective Laser Sintering; e) SLM – Selective Laser Melting / Direct Metal Laser Sintering; f) 3DP – Printare inkjet 3D; g) LOM – Laminated Object Manufacturing; h) PJP – PolyJet Printing [4].

Thermoplastic Extrusion (molten material deposition) modeling is the most widely used additive manufacturing technology and is utilized in modeling, prototyping, as well as production applications. Due to the availability of numerous patents in the public domain since the 1980s, as well as the simplicity and accessibility of this technology, many manufacturers of affordable 3D printers have emerged.

3D printing through molten material deposition, such as Fused Deposition Modeling (FDM), are technologies that frequently employ fill materials of various origins and categories to enhance print quality. A significant category of materials found in the composition of filaments and inks used in these two technologies consists of textile fibres. The complexity of the chosen solution for the print differs depending on the intended use. As shown in figure 1, in the case of FDM printing, the choice of thermoplastic polymer is of particular importance as it directly influences the working temperature, production costs, and the performance of the obtained product.

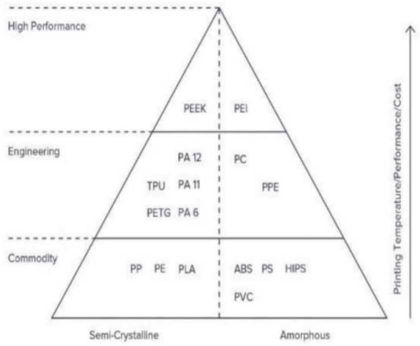

Figure 1. Categorization of 3D Materials by Field of Application [5]

The purpose of this study is to synthesize the research conducted in the academic environment and to analyse the impact on the physical and mechanical properties of the print based on the type and origin of the textile fibres used as fill materials within the filaments used in 3D printing.

2. FILLER MATERIALS

Composite filaments used in 3D printing (Fused Deposition Modeling - FDM) consist of a thermoplastic polymer matrix and one or more filler materials. Filler materials must meet several requirements [6]: i) *compatibility with the matrix polymer*: They should exhibit stability under heat and light and not influence the stability of the polymer; ii) *wettability*: Good adhesion of fibres/powders to the base polymer; iii) *uniformity* in the quality and size of the filler materials. These are inert substances added to the base polymer with the aim of significantly modifying mechanical, electrical, or thermal properties. Sometimes, they serve the simple purpose of improving the surface appearance or reducing the production cost of the composite material obtained [7], [8], [9]. The choice of filler substances is based on the properties that need to be altered in the designed composite material.

Filler materials come in various types: i) *organic*, such as cellulose-based materials (vegetable fibres, wood flour, fruit peel) and starches [6]; ii) *minerals* (talc, titanium dioxide, carbonates, silica, nanotubes, etc.) [6], [10]. The role of these materials is to enhance the strength, elasticity, production cost, and biodegradability of products obtained by combining thermoplastic polymers with these materials.

Textile fibres are a widely discussed topic in research related to their use in 3D printing due to their versatility. They can serve various roles depending on the type of polymer used, especially in the case of petroleum-based polymers (PP, PA, ABS, HDPE, PVC), where they contribute to increased biodegradability through the addition of organic filler materials and improvements in the mechanical properties of the print. In the case of adding mineral or organic fibers to biopolymers (PLA), significant enhancements of product properties have also been observed.

The main drawbacks of using fibres as filler materials, regardless of their nature, include: a) specific mechanical or chemical treatments for increasing compatibility and wettability with the utilized polymer; b) the use of plasticizers and lubricants to enhance the composite's fluidity; c) all of these aspects require careful environmental impact studies to verify and justify the feasibility of using these types of filling materials.

3. TEXTILE FIBERS USED IN 3D PRINTING

3.1. Fibres Used in 3D Printing.

The concept of fibre has been assigned to solid bodies whose transverse dimensions are very small, in the order of microns, much smaller than their longitudinal dimensions. Textile fibres are those fibres available in a sufficiently large quantity and possessing a set of properties that make it possible to transform them into textile products and confer specific characteristics to the final product in the respective field of use.

Figure 2 shows a schematic representation of an extrusion machine for producing filaments from thermoplastic polymers blended with various fillers used in fused deposition modeling.

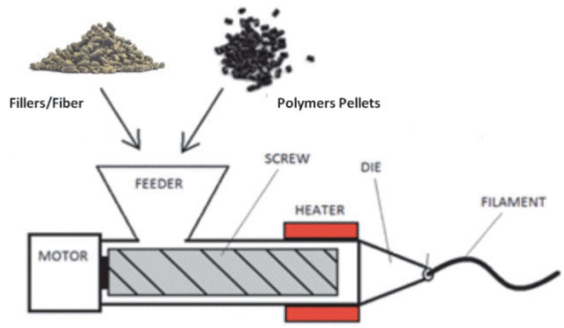

Figure 2. Schematic representation of a screw extrusion machine used to produce thermoplastic filament with added fillers for 3d printing [11]

The fibers used as filler materials, with the purpose of enhancing print quality, are highly diverse, including both mineral, chemical, and natural fibers. To ensure the uniform distribution of these fillers within the mass of printable filaments, mechanical processing operations are required, involving the grinding of these materials to the necessary volume dimensions for optimal mixing with the matrix polymers. Chemical treatments and fiber conditioning are aspects that significantly improve interfacial bonds and reduce fiber-polymer tensions. The hydrophilic nature of natural fibers or the hydrophobic nature of mineral/synthetic fibers, combined with the hydrophobicity of thermoplastic polymers, inherently leads to issues of polarity, causing weak interfacial bonds within the designed composite material. The selection of an appropriate polymer, the modification of the contact surface, and the quantity of added fibers can contribute to improving the bonds between fibers and polymers, with positive repercussions on the mechanical properties of the designed print.

The use of high-performance fibers such as carbon, Kevlar, and glass fibers as filler materials aims to enhance the mechanical performance of printed products.

After researching the use of carbon fiber as reinforcement for various plastic materials, such as ABS, in the context of 3D printing, the following conclusions can be drawn: i) *advantages of Chopped Carbon Fiber (CF)* - The use of chopped carbon fiber as reinforcement offers several advantages, including cost reduction in production, improved thermal resistance and rigidity, weight reduction, and the achievement of a smooth surface finish. This technique is popular in 3D printing with plastic materials [12]; ii) *impact of CF Content on ABS* - Various studies have analyzed the impact of CF content on the microstructure and mechanical characteristics of ABS. In general, adding CF to ABS has improved the strength and modulus of composite materials, but high CF concentrations can lead to porosity and matrix weakening, thus affecting performance [13]. According to the characterization tests mentioned, adding 15% CF to PLA resulted in significant improvements in tensile strength and Young's modulus of the material. These findings are consistent with previous research which showed similar enhancements in the mechanical properties of CF-PLA composites [14].

The impact of layer thickness on the mechanical properties of printed parts indicates that thinner walls exhibit better mechanical properties [15]. It should be emphasized that the addition of CF generally improves tensile strength but reduces elongation at break and creates a low interfacial shear strength [16].

Importance of Recycling in the Carbon Fiber Industry - The significance of recycling in the carbon fiber industry highlights the benefits of recycling CF from Continuous Fiber Reinforced Polymer Composites (CFRP) waste, especially in terms of enhancing mechanical performance and reducing environmental impact [17]. Chemical recycling processes and solvolysis methods are presented as promising solutions for CF recovery from composite waste [18], [19]. It is noted that recycling plastic waste by adding CF and using it as a raw material in FDM has the potential to reduce waste and promote a circular economy [20].

Also, the text sequence ‘the thematic evolution of textile fibers used in 3D printing’ was analyzed by searching in the Clarivate Analytics database, in the "topic" section, resulting in a total of 248 scientific publications. To study the scientific development of this field, we decided to utilize thematic maps as a tool. A thematic map describes the evolution of the scientific domain, and its connections are presented in the form of a network. The data downloaded from Clarivate Analytics in the form of a text file were inputted for analysis into R-Stata Bibliometrix [21] which is specialized in Science Mapping Workflow.

Figure 3 presents the year-by-year evaluation of the 248 resulting articles, and it can be observed that the field began its evolution in 2011, being relatively new in the realm of chemistry or textile publications. It maintained a relatively constant structure until around 2018, with approximately 10 scientific results per year, likely due to its novelty or the rapid technological innovations in the 3D printing field, both in software and hardware. Starting from 2018, there is a noticeable increase in scientific articles on this subject, reaching nearly 50 per year in 2022.

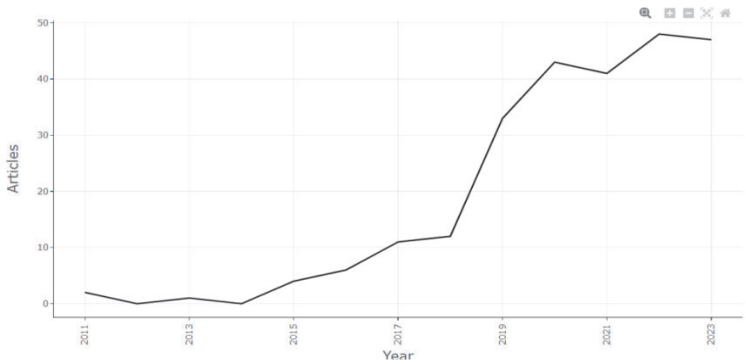

Figure 3. Annual scientific production, from textile fibers in 3d printing

Source: authors’ own processing in R-Stata Bibliometrix

The connections between different domains, identified by R-Stata Bibliometrix within the abstracts, titles of the 248 articles, are presented in the form of a Co-occurrence network. This network is a method for analyzing text that provides a visual representation of potential relationships between the most frequently used words in the given text, in this case, the words from titles and abstracts. The most frequently used words include "printing," "materials," "printed," "properties," "textile," "applications," etc. (Figure 4).

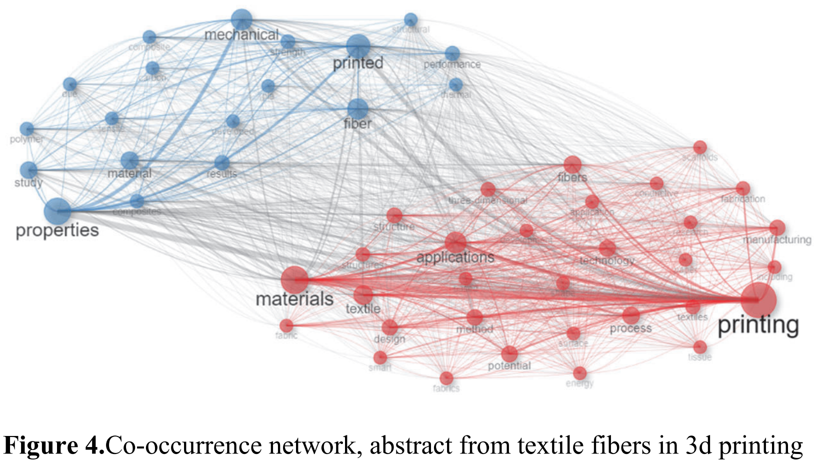

Figure 4. Co-occurrence network, abstract from textile fibers in 3d printing

Source: authors’ own processing in R-Stata Bibliometrix

This indicates that as 3D printing hardware technologies continue to advance, textile fibers become increasingly exciting, and some of the older themes are already foundational. It also reflects the dynamic nature of research in this area and the evolving landscape of opportunities for exploration and innovation.

3.2. Wires Used in 3D Printing

A wire is an assembly of fibers that are arranged or twisted together to form a continuous strand. Wires can be made from either discontinuous fibers or filament fibers. Discontinuous fibers are twisted into wires, while filament fibers require little or no twisting to hold them together as a strand.

In 2014, with the patenting and prototyping of a 3D printer for Continuous Fiber Reinforced Polymer Composites (CFRP), a new era was ushered in the prototyping industry. This innovation allowed for 3D printing with continuous wire used as a reinforcement element for thermoplastic or thermosetting polymer. Thus, wires made from fibers like jute, flax, hemp, as well as monofilament or multifilament fibers of carbon, glass, Kevlar, or polyethylene, either directly fed into the printing nozzle or pre-impregnated with polymers, bestowed improved performance characteristics on the resulting product at reduced costs. This printing method delivers products with enhanced mechanical properties compared to those containing short fiber fillers.

Figure 5 schematically illustrates the two methods used for 3D printing with continuous wire: a) the preparation of pre-impregnated continuous wire filament to be fed into a 3D printer and b) schematic representation of a printer that can be directly fed with the reinforcement wire filament at the extrusion nozzle.

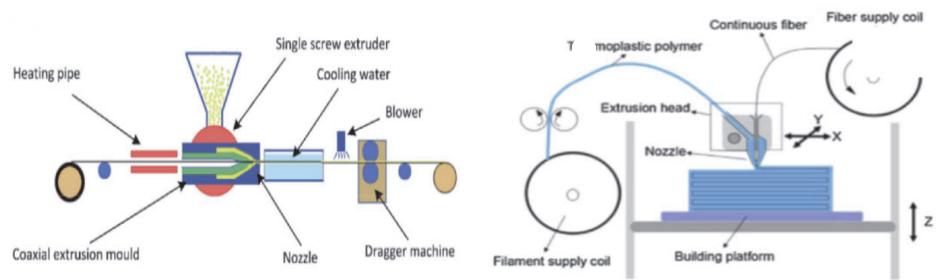

Figure 5. a) Schematic of melted polymer pre-impregnating process [22] b) Schematic representation of the 3D printing process for continuous fiber reinforced thermoplastic composites (CFRTPCs) [23]

The main efforts have been to improve the interface between wires/filaments and matrix polymers, which is why a series of adaptations to the printing method are necessary, such as laser-assisted preheating [24], plasma treatment [25] or microwave treatment [26]. Carbon and Kevlar filaments, characterized by exceptional strength and rigidity but also high cost, are used in aerospace and automotive industries. Glass fibers, being more cost-effective, find applications in the sports industry. Natural fibers like jute, hemp, and flax are used in green composites. The search for materials suitable for 3D printing has led to numerous studies on various characteristics of carbon fibers. Dickson investigated and compared nylon composites reinforced with continuous carbon, glass, and Kevlar filaments using the additive manufacturing technique of fused deposition modeling. The results indicated that the tensile strength obtained for all these variants surpasses that of aluminum and is over five times greater than the control samples made from nylon [27]. Other research work, coordinated by Tian, Continuous fiber reinforced polymer composites have been used in different industries (automobile, aircraft, and space) with high specific strength, and modulus in comparison with the metals they replaced. These properties make this fiber very reliable for 3D printing, who open a new era in design and printing composite structures at low-cost [28]. Following the investigation done by Terekhina and his colleagues on continuous printing of bleached flax wire with polyamide matrix, they observed the improvement of the tensile strength by 2.4 times and the modulus of elasticity by nine times, compared to the control sample. [27]. Blok et al. have comparatively investigated the performance of two solutions, namely printing with short carbon fiber reinforced nylon filament and continuous carbon polyfilament reinforced nylon filament. They concluded that continuous printing with carbon polyfilament provides products with significantly superior tensile strength and stiffness characteristics. The combination of the two methods could eliminate some disadvantages of continuous filament printing by making a thermoplastic filament that uses short fibers and continuous polyfilaments as reinforcement, thus improving the quality of the printed product [29].

Matsizaki et al., investigated jute wire printing with PLA matrix, and reported a 157% increase in the elasticity modulus and a 134% increase in tensile strength compared to the standard PLA 100% [30].

The text sequence ‘thematic evolution of wires used in 3D printing’ was analyzed by searching for it the Clarivate Analytics database, in the "topic" section, resulting in a total of 752 scientific publications, 518 articles, 206 proceedings paper, 37 review articles, 10 early access. Using the same methodology, the extracted data was entered into R-stata bibliometrix, and the results are presented in the form of trend graphs for the field. Similar to the evolution of articles on the topic of "fibers in 3D printing," the trend for "wires in 3D printing" is approximately the same. There was a lower number of publications until 2013, after which the trend has been steadily increasing, reaching over 120 publications per year in 2022 (Figure 6).

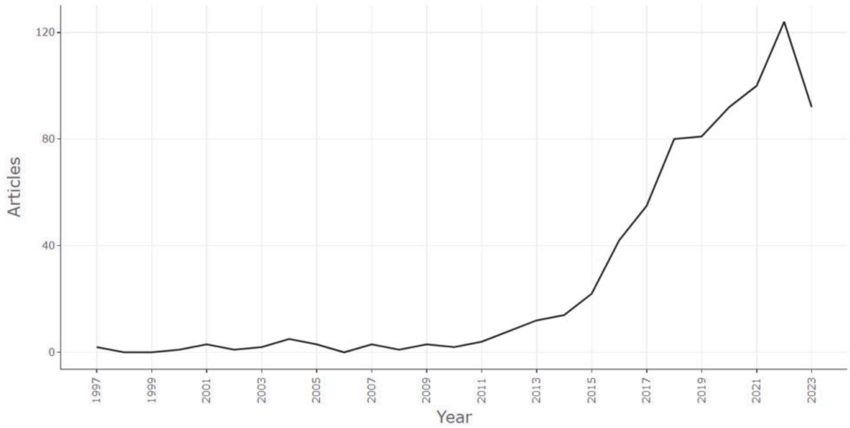

Figure 6. Annual scientific production, from wires in 3d printing

Source: authors’ own processing in R-Stata Bibliometrix

The thematic evolution of abstracts related to "wires in 3D printing," analyzed using R-Stata Bibliometrix using 2-grams (sequences of two words or features that occur together in the same sentence) and presented in Figure 7, highlights the research directions in this field. In the initial period from 1997 to 2018, the focus was on "electronic devices," "additive manufacturing," "printed circuit," and "printing wiring." In the second period from 2019 to 2020, there was a continuation of these directions, with some new developments, such as "additive manufacturing," "printing technology," "fabrication process," "low cost," and "conductive wire," among others. In the most recent period from 2021 to 2023, we observe that the field maintains its core directions while also showing new developments like "computed tomography," "photonic wire," "polylactic acid," "shape memory," and more.

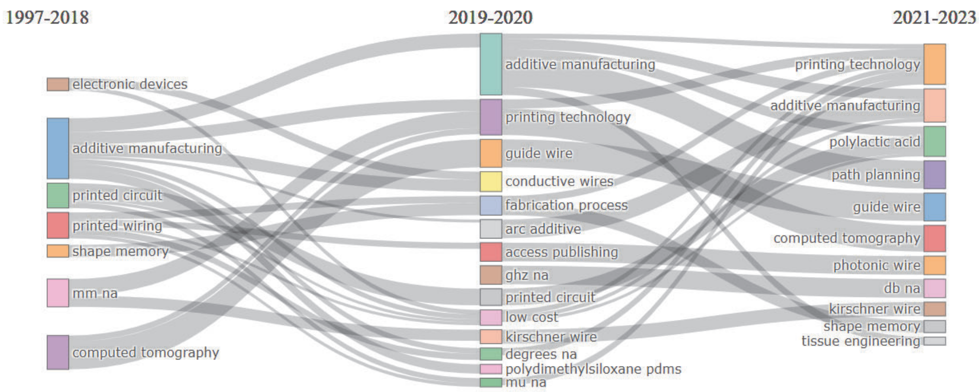

Figure 7. Thematic evolution of abstracts from articles wires in 3d printing

Source: authors’ own processing in R-Stata Bibliometrix

The analysis of the first period from 1997 to 2018 reveals several key thematic areas. In the field of electric circuits, there are themes related to "printed circuits" and "circuit boards". The second period, from 2019 to 2020 is characterized by a surge in thematic directions, highlighting the fact that the field is dynamic and attractive to researchers, journals, and potentially the industry. The size of the circles indicates a concentration on several key themes, many of which are related to "additive manufacturing" and its relationship with economic aspects such as costs and raw materials. The core themes continue to revolve around printing and scanning technologies. Notably, emerging themes such as "industrial applications," "power module," and "acquisition systems" are of particular interest in this graph. In the third period, 2021-2023, the graph is filled with various directions, and it's clear that multiple domains are evolving.

4. CONCLUSIONS

As shown in this review, despite the growing interest in FDM 3D printing and its applications in various fields such as prototyping, electronics, biomedicine, and the production of finished products, there are still several challenges that hinder widespread adoption. These challenges include:

- Complex Equipment and Design Costs: The design of products and 3D printing equipment involves complex tools and machinery, which can result in high material, design, and maintenance costs to achieve optimal results.
- Time-Consuming Process: Depending on the complexity of the requirements, the 3D printing process can be time-consuming. This may be justified in prototyping but can be a hindrance in large-scale production, where traditional methods are often faster.
- Limitations in Printing Large Structures: Printing large or very large structures is limited by the current technology, which can be a drawback for certain applications.
- Lack of Standardization: Industry and research standardization for consumables, such as polymers, and commercial 3D printing applications are still lacking. This lack of standardization can hinder compatibility and the broader adoption of 3D printing.
- Structural and Material Compatibility Challenges: Achieving optimal structural performance, layer adhesion, and compatibility between polymers and various reinforcement structures or fillers remains a challenge that researchers are actively addressing.

From an environmental perspective, 3D printing offers the potential to reduce waste and lower transportation costs through local production, especially for customized products. This aspect can have a positive impact on reducing the environmental footprint.

In conclusion, applications involving fibers, wires, and their derivatives, as well as the optimal polymer matrix for maximizing the potential of this combination, remain an open area of research in the field of 3D printing. We believe that the diversity of textile fibers can open up numerous research opportunities and significantly contribute to the development of the rapid prototyping industry.

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ELECTROSPUN NANOFIBERS IN THERMOELECTRIC ENERGY HARVESTERS: A REVIEW

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***Abstract**. In the current context of heightened pollution and energy shortages, the pursuit of alternative and environmentally friendly energy sources represents a notable challenge for researchers. Moreover, the expansion of portable electronic devices in recent years has significantly raised the demand for portable and flexible power generators, particularly for those electronic devices that need continuous operation (e.g., implantable cardiac devices, hearing aids, fitness trackers, etc.). In this regard, thermoelectricity, which involves the direct conversion of temperature gradients into electricity without the need for moving parts or working fluids, is considered an exceptionally attractive solution to address these pressing concerns. Currently, the utilization of a fiber-like form factor has emerged as a fresh and adaptable strategy in thermoelectric design. Conductive polymers (CPs) offer promising prospects as organic semiconductors for thermoelectric applications due to their adjustable physical and chemical characteristics, good biocompatibility, mechanical flexibility, lightweight nature, and scalability manufacturing processes. Despite these advantages, CPs have not fully accomplished their potential in traditional manufacturing techniques. Electrospinning, a straightforward and highly adaptable method, presents an opportunity for the mass production of continuous ultrafine thermoelectric fibers from a wide range of polymers. Electrospun fibers offer several advantages, including uniformity, porosity, substantial surface area, and mechanical strength. These attributes open up new avenues for the application of CPs and address numerous challenges associated with their use. However, electrospinning CPs, which are soluble and brittle by nature, require a specialized approach. Various strategies have been developed to tackle this issue, including direct electrospinning of conductive polymers, co-electrospinning of mixtures involving conductive and nonconductive polymers, and the synthesis of nanofiber templates. This article presents a comprehensive review of polymeric nanofiber used in thermoelectric energy harvesters. More emphasis is placed on the fabrication methods, properties, and applications of nanofiber conductive polymers in thermoelectric energy harvesters, providing insights into their potential for efficient and sustainable energy generation.*

***Keywords:** nanofibers, electrospinning, conductive polymers, thermoelectric materials.*

1. INTRODUCTION

Energy harvesting refers to the process of capturing and converting ambient forms of energy from the surrounding environment into usable electrical power. This approach enables the generation of electricity without relying solely on traditional power sources like batteries or electrical outlets. Some common sources of energy that can be harvested include Solar Energy, Thermal Energy, Mechanical Energy, Vibration and Motion Fluid Flow, etc. Solar panels are a well-known example of solar energy harvesters.

The human body and its environments, including body heat, sunshine, and biomechanical motions, are abundant sources of sustainable energy [1]. Over the past few years, many wearable devices have emerged to capture such forms of energy, including solar cells (SCs), thermoelectric generators (TEGs) triboelectric generators (TENGs), and piezoelectric nanogenerators (PENGs). Nevertheless, these electric generators display specific weaknesses when it comes to powering wearable electronics. Their structural designs characterized by thickness and bulkiness render them uncomfortable to wear. Therefore, producing sustainable energy without affecting human comfort continues to be a challenge for wearable energy harvesters.

Wearable thermoelectric harvesters are devices or technologies designed to capture and convert energy from the wearer's body temperature into electrical power. These wearable devices are typically integrated into clothing, accessories, or worn on the body and serve to power or recharge other wearable electronics, such as smartwatches, fitness trackers, or medical devices. The goal of wearable energy harvesters is to reduce the reliance on traditional batteries and extend the operational life of wearable devices, making them more convenient and sustainable. The use of new semiconductor materials based on conductive polymers (CPs) is considered a promising solution for the development of alternative energy sources, particularly renewable and environmentally friendly ones.

The body's wasted heat could be transformed into electrical energy via thermoelectric materials. The Seebeck effect, which was discovered in 1821 [2], enables the direct conversion of a temperature gradient into electrical energy without the necessity of moving components or working fluids. To assess the efficiency of this energy conversion process, a dimensionless figure of merit known as ZT is employed. ZT is calculated as $ZT=S^2 \cdot \sigma \cdot T/\kappa$ and is dependent on the intrinsic characteristics of the materials used, such as electrical conductivity (σ), Seebeck coefficient (S), and thermal conductivity (κ) [3].

To achieve efficient thermoelectric performance, it is crucial to have higher electrical conductivity and Seebeck coefficient, while minimizing heat transfer. Nevertheless, the interdependence of these parameters has constrained the growth of ZT values [4]. Despite this, the maximum ZT value is achieved through a compromise between the values of these electrical properties [5]. Currently, the development strategies for new thermoelectric materials consider the need to break down this strong interdependency among the transport properties (σ, S, or κ) [6]. In this regard, fiber-based materials emerge as promising candidates for enabling the green conversion of wasted energy.

Historically, the best values of the figure of merit, ZT, have been achieved using crystalline compounds such as Bi_2Te_3 [7], PbTe [8], or SnSe [9]. However, despite their high thermoelectric properties, the real-world uses of these materials remain constrained due to factors such as production costs, toxicity, weight, and scarcity [10], [11]. As a result, there is a growing interest in exploring alternative thermoelectric materials that can overcome these challenges. Recently, there has been a notable focus on conductive polymers.

Polymers have aroused special interest in many scientific fields since their appearance at the beginning of the last century, but their use in energy harvesting was possible only after the discovery of CPs [12]. Over the last ten years, there has been a noteworthy increase in the interest surrounding CPs for thermoelectric applications. This is primarily due to their semiconducting nature, which is achieved through the presence of delocalized π electrons along the polymer chain. The distinct molecular configurations of CPs, characterized by sp^2 hybridization and backbones, facilitate the excitation of π bond electrons, enabling efficient charge transport along the polymer backbone [13]. Several CPs have gained prominence in thermoelectric applications. These include Polypyrrole (PPY), Polyaniline (PANI), Polyacetylene (PA), Polythiophene (PTH), Poly(3,4-ethylenedioxythiophene): Poly(styrenesulfonate) (PEDOT: PSS). Following the doping process, many CPs exhibit noteworthy electrical conductivity values exceeding 1000 $S \cdot cm^{-1}$. Moreover, they demonstrate relatively low thermal conductivity ranging from 0.1 $W \cdot m^{-1} \cdot K^{-1}$ to 1 $W \cdot m^{-1} \cdot K^{-1}$ when compared to inorganic thermoelectric semiconductors, which typically exhibit thermal conductivities of 1-100 $W \cdot m^{-1} \cdot K^{-1}$ [14]. Notably, the highest electrical conductivity values are achieved with p-type (hole-transporting) conjugated polymers.

Reducing the size of materials to a nanometric scale, as exemplified by the electrospinning process, can enhance the thermoelectric parameters as a result of an alteration in both the transport of charge carriers and electrical conductivity [15].

2. THERMOELECTRICITY

2.1. General scientific concepts

As a practical approach to energy harvesting, only two thermoelectric (TE) devices are of particular importance: the thermoelectric generator, based on the Seebeck effect (Figure 1. a), and the active cooler, based on the Peltier effect (Figure 1. b). These devices have attracted significant attention in the context of the ongoing energy crisis. These devices typically employ semiconductors due to their significantly superior thermoelectric characteristics compared to metals. The Seebeck and Peltier effects, although distinct manifestations, actually originate from the same underlying physical process. In certain cases, they are interconnected and referred to as the Seebeck-Peltier effect [16].

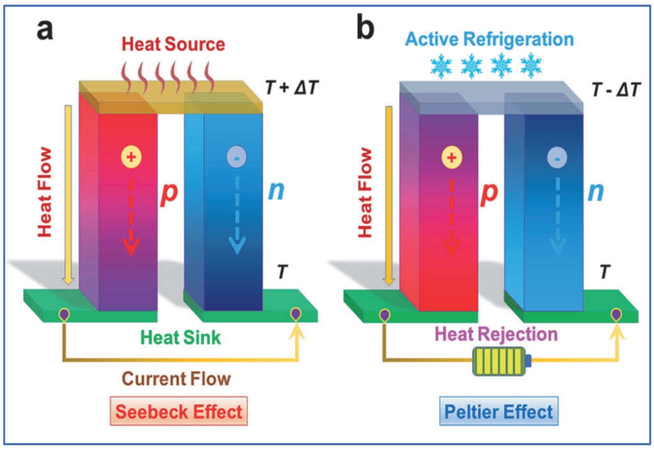


Figure 1. Thermoelectric phenomena illustrated in schematic diagrams showing the Seebeck effect (a), and the Peltier effect (b). The figure is adapted from [17].

When a TE material is part of a closed electrical circuit, we have both an electrical current density, J, and a thermal current density, J_Q, as a combination of electrical field $\mathbb{E}$, electrical conductivity, σ, Seebeck coefficient, S, thermal conductivity, k, and temperature gradient dT/dx [18]:

$$J = \sigma \cdot \mathbb{E} - (\sigma S)\frac{dT}{dx} \tag{1}$$

$$J_Q = (T\sigma S) \cdot \mathbb{E} - k\frac{dT}{dx} \tag{2}$$

According to the Landauer-Boltzmann approach, when there is a variation in the Fermi function at the ends of the thermoelectric (TE) material, an electric current emerges. The difference (f_1 - f_2) can be driven by differences in electrochemical potentials, but it could just as easily be driven by a temperature gradient. The resulting current has a general form [19]:

$$I = \frac{1}{q}\int_{-\infty}^{+\infty} G(E)(f_1 - f_2)dE \tag{3}$$

where $G(E)$ is the conductance function and, $f_{1,2}$ - Fermi function distribution of electric carriers.

3.1. Conductive polymers

In contrast to inorganic crystalline materials, polymers possess a non-crystalline structure, making the band theory unsuitable for conductive polymers. Saturated polymers, classified as insulating materials, comprise atoms that are covalently bonded to sp^3 hybridized carbon atoms. The electrons involved in these bonds occupy low-energy levels, resulting in limited electric conductivity. Conversely, CPs feature sp^2 hybridized carbon atoms. Each carbon atom forms three σ-bonds, constituting the polymer chain's structure, while one 2p electron becomes delocalized within perpendicular π-orbitals. These π orbitals overlap across carbon atoms, facilitating enhanced mobility of the delocalized electrons along the polymer's backbone. As a result of the Peierls instability, a feature observed in one-dimensional electron-lattice systems, the π band undergoes a split, resulting in two bands (π and π*) with an energy gap, Eg, in the excitation spectrum that spans from 1 eV to 4 eV [20]. This energy distribution closely resembles the energy bands found in classical semiconductor materials, in which the bonding orbital corresponds to the valence band known as the Highest Occupied Molecular Orbital (HOMO), and the anti-bonding orbital corresponds to the conduction band referred to as the Lowest Unoccupied Molecular Orbital (LUMO). Doping techniques like p-type and n-type doping enable the control of charge carriers and facilitate the enhancement of thermoelectric performance. The molecular doping technique in conductive polymers involves an oxidation/reduction reaction that generates charge carriers, such as polarons (radical ions), bipolarons (dications or dianions), or solitons within the polymer. This process leads to an enhancement in electrical conductivity [21]. Figure 2 shows the transformation of the band structure as the number of repeated units increases.

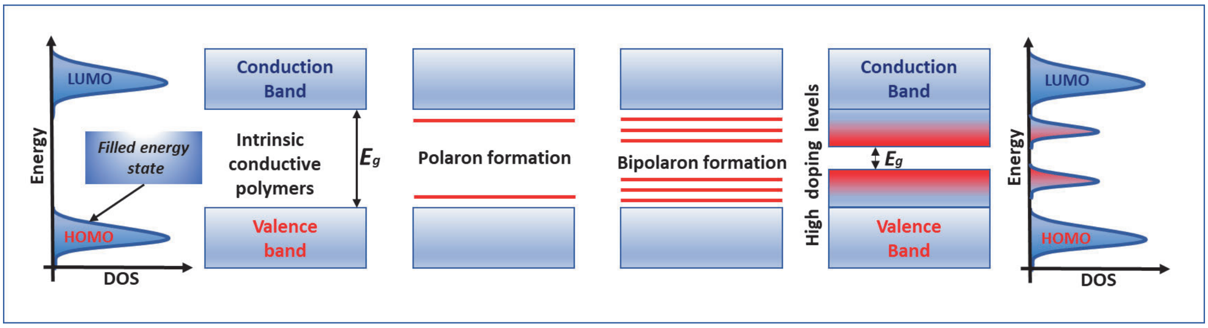


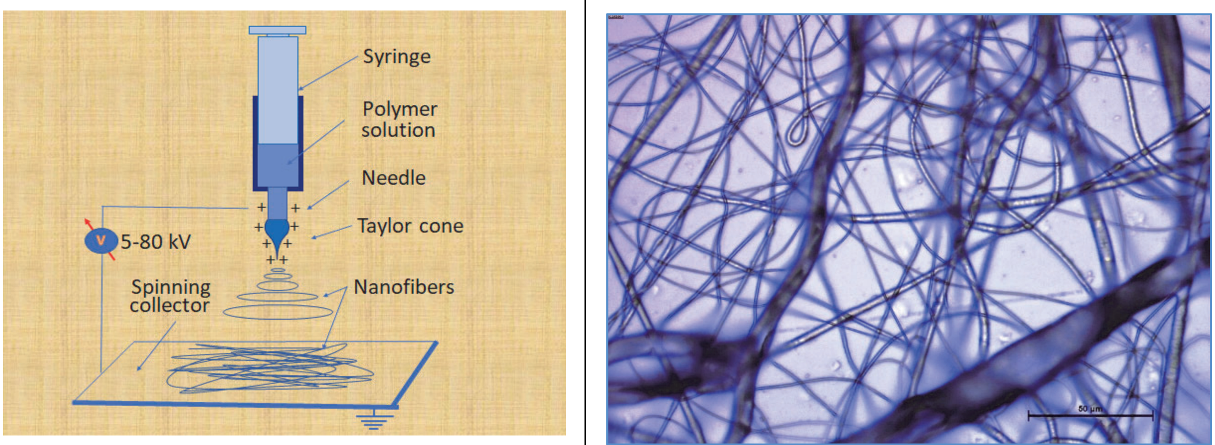
Figure 2. Illustrative representation of the energy band structures for conductive polymers at various doping levels. The figure is adapted from [20].

3. ELECTROSPINNING THERMOELECTRIC NANOFIBERS

The choice of a particular method to obtain thermoelectrical nanofiber mats depends on various considerations, such as the desired characteristics of the nanofibers, material compatibility requirements, and the availability of suitable equipment for the fabrication process. In the field of materials science and energy harvesting, electrospun thermoelectric nanofibers have emerged as an exciting and innovative solution. Electrospinning represents a promising technology for the efficient conversion of waste heat into usable electrical power, with applications ranging from wearable devices to remote sensors. Typically, the electrospinning of polymer solutions yields nanofibers, which are subsequently subjected to post-treatment to enhance their electrical properties.

Electrospinning is a commonly employed dry-spinning technique for producing continuous polymeric nanofibers or nanofiber mats. These materials typically exhibit dimensions approximately 10^2 - 10^4 times smaller than those achieved through conventional methods [22]. In a standard electrospinning procedure, a syringe is loaded with a highly viscous polymer solution, and a high voltage is applied between the syringe needle and a collector. The electric field causes a fine jet of polymer to be ejected from a spinneret, resulting in the formation of ultrafine fibers that are collected as a non-woven mat on a grounded collector. By incorporating additives or doping agents, electrospinning enables the fabrication of polymeric nanofiber mats with tailored thermoelectric properties.

This versatile spinning method allows for control over the fibers' morphology such as composition, diameter, or orientation of the obtained fibers [23]. Figure 3. a) illustrates the basic electrospinning setup, while Figure 3. b) presents a microscopic image of electrospun polyvinyl alcohol (PVA) nanofibers.



a) b)

Figure 3. Schematic configuration of electrospinning process and Taylor cone generation (a), and microscopic image of PVA nanofiber obtained by the electrospinning process (b).

The electrospinning method is applicable to nearly any high molecular weight and soluble polymer. Nonetheless, producing fine nanofibers necessitates meticulous attention to operating parameters and solution characteristics, including applied voltage, spinning distance, solution feed rate, air humidity, solution viscosity, solution conductivity, and other factors [24].

Currently, there are several variations of electrospinning techniques such as coaxial electrospinning, solution blow spinning, Forcespinning®, and template-assisted electrospinning. *Coaxial electrospinning* is a technique that enables the encapsulation of one material within another to create core-shell structured nanofibers. In this method, two or more polymer solutions with different compositions are coaxially electrospun through concentric spinnerets. The inner solution forms the core, while the outer solution forms the shell of the nanofiber. By incorporating thermoelectrically active materials in the core or shell, coaxial electrospinning can be utilized to fabricate nanofiber mats with enhanced thermoelectric properties. *Solution blow spinning*, also known as electrostatic spinning or air blow spinning, is a variation of the electrospinning technique. It involves the extrusion of a polymer solution through a spinneret nozzle while applying a high-pressure gas stream, typically compressed air, to induce the formation of fibers. The fibers are collected as a mat on a substrate. Solution blow spinning offers advantages such as simplicity, scalability, and the ability to process a wide range of polymers, making it suitable for the fabrication of thermoelectric nanofiber mats. *Forcespinning®* is a patented electrohydrodynamic (EHD) technique that combines elements of electrospinning and centrifugal spinning. In this method, a rotating spinneret is used to extrude a polymer solution, while an electric field is applied to generate a jet of charged solution. The combination of centrifugal and electric forces leads to the formation of ultrafine fibers that are collected as a nanofiber mat. Forcespinning® offers control over fiber diameter and alignment and can be used to produce thermoelectric nanofiber mats with improved properties. *Template-assisted electrospinning* involves using a template or sacrificial material to guide the formation of polymer nanofibers with specific structures or patterns. The template can be a sacrificial polymer, a porous material, or a pre-patterned substrate. The polymer solution is electrospuned onto or around the template, and after solidification, the template is removed, leaving behind a nanofiber mat with the desired structure. Template-assisted electrospinning allows the fabrication of thermoelectric nanofiber mats with controlled pore sizes, orientations, or arrangements, which can impact their performance.

The electrospinning technique has only recently gained significant attention in the field of thermoelectric materials. Maensiri and Nuansing [25] achieved a groundbreaking milestone by fabricating TE nanofibers through electrospinning. They used polyacrylonitrile as the polymer matrix and a mixture of cobalt acetate/sodium acetate as a filler. Subsequently, they performed calcination to obtain sodium cobalt oxide nanofibers with diameters ranging from 20 to 200 nm.

Yin et al. [26] conducted a study where they synthesized calcium cobalt oxide nanofibers with an approximate diameter of 350 nm using a sol-gel-based electrospinning technique resulting in ceramic material exhibiting significantly smaller grain sizes compared to the bulk material and showed a 55 % enhancement in the figure of merit (ZT) at 975 K, reaching approximately 0.4.

Xu et al. [27] achieved also a favorable outcome in their research. They reported the synthesis of p-type perovskite oxide ($La_{0.95}Sr_{0.05}CoO_3$) nanofibers with a Seebeck coefficient (S) of 650 $\mu V \cdot K^{-1}$ at room temperature. Notably, this value was higher than that observed in thin films or bulk forms.

In a more recent development, Park et al. [28] achieved the synthesis of lead telluride (PbTe) hollow nanofibers using a combination of three distinct processes: electrospinning, electrodeposition, and cationic exchange reaction. The resulting nanofiber mats demonstrated an S value of 433 $\mu V \cdot K^{-1}$ at 300 K, along with a PF reaching 0.567 $\mu W \cdot m^{-1} \cdot K^{-2}$.

Although the nanofibers presented above demonstrate exceptional thermoelectric properties, it is important to highlight that they are not composed of environmentally friendly materials. To embrace eco-friendly solutions, researchers have recently directed their attention towards nanofibers derived from conductive polymers like Poly(3,4-ethylenedioxythiophene): Polystyrene sulfonate (PEDOT: PSS), which are doped with nanoparticles that exhibited remarkable electrical conductivity to enhance their TE properties [29]. The Internet of Things (IoT) concept has also motivated extensive research on organic thermoelectric materials, finding wide applicability in wearable electronics, smart fabrics, and implantable medical devices [30].

Shengnan et al. [31] introduced an innovative method involving the electrospinning of PEDOT: PSS/PVA, coupled with the in-situ synthesis of silver nanoparticles (Ag NPs) as a subsequent treatment step to boost the thermoelectric properties of composite nanofibers films. The introduction of Ag NPs led to a substantial enhancement in electrical conductivity from 0.67 to 41.5 $S{\cdot}cm^{-1}$. Consequently, this approach yielded a maximum power factor of 1.2 $\mu W{\cdot}m^{-1}{\cdot}K^{-2}$ at room temperature.

A new approach was implemented by He et al. [32]. They combined a self-assembly strategy along with wet electrospinning in a coagulation bath to effectively fabricate CNTs/PEDOT: PSS nanofiber mats. These nanofibers exhibited remarkable stretchability of approximately 350 % along with a high thermoelectric property. The achieved Seebeck coefficient was 44 $\mu V{\cdot}K^{-1}$, while the power factor and electrical conductivity attained values of 5.4 $\mu V{\cdot}m^{-1}{\cdot}W^{-2}$ and 26.4 $S{\cdot}cm^{-1}$, respectively.

Jiang et al. [33] employed electrospinning to produce composite nanofiber mats by incorporating one-dimensional carbon-doped boron nitride nanotubes (BCNNTs) into PVA/PEDOT: PSS. A notable improvement in the thermoelectric properties of the folded multilayer BCNNTs/PVA/PEDOT film was observed. The film exhibited a Seebeck coefficient reaching 3.62 $mV{\cdot}K^{-1}$, although the power factor remained relatively low at 29.09 $nW{\cdot}m^{-1}{\cdot}K^{-2}$.

4. CONCLUSIONS

Nanofibrous materials hold great promise for addressing critical issues such as waste energy recovery. Various techniques can be employed to produce nanofibrous materials, but the electrospinning method in particular has garnered significant attention. These methods offer distinct advantages, including minimal thermal degradation and the ability to control the diameter of the produced fibers. Electrospinning, in particular, stands out as a versatile approach capable of producing nanoscale conductive polymer fibers. The one-dimensional structure of these fibers contributes significantly to enhancing the TE efficiency of fibrous materials, thanks to effects such as energy filtering, quantum confinement, and improved phonon scattering. Furthermore, the thermoelectric properties of nanomaterials can be enhanced through compositions involving the combination of organic and inorganic nanofibers, along with subsequent post-treatment.

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CARBON FOOTPRINT OF RECYCLED RAW MATERIALS FROM TEXTILE WASTE IN A NEW PRODUCT LIFE CYCLE

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Abstract. The fashion industry promotes a fast consumption pattern of various textile items, all intentionally projected for a short lifespan. More exactly, in the apparel industry, the trend of so-called fast fashion is developing through the frequent substitution of clothing whose accessibility and affordability leads to an increase in the quantities of textile materials used and, consequently, in the quantities of textile waste before and after consumption. At the moment, the textile waste recycling sector is currently characterised by a relatively early stage of development, and its recovery as a raw material for new applications is limited by a clear lack of correlation between present recycling techniques and the profitability of manufacturing new items on a large industrial market. The purpose of the paper is to present the environmental implications of recycled raw material in a new product life cycle using life cycle assessment evaluation. The paper presents a review of different methodological assumptions used in LCA studies on recycled raw material which can influence the result of the LCA study due to the input data allocation. The most common approach in the literature assumes that recycled raw material is equivalent to virgin raw material, which involves adopting the cut-off scenario allocation in carbon footprint impact. Furthermore, there is also a strong argument against this approach, depending on the type of recycling (up or downcycling), where the environmental impact of recycled raw material should be integrated, positive or negative impact, into the LCA evaluation.

Keywords: life cycle assessment, textile waste, recycling process, downcycling.

1. INTRODUCTION

Textile waste consist in pre- and post-consumer which is a highly valuable raw material resource. Extending the life cycle by using these raw materials in a cascading manner demands a multi-sectoral approach. Finding the optimal recovery direction to follow requires a multi-step approach to recycling. In terms of environmental impact, research reveals that the reuse of textile waste is less polluting than recycling because it increases the lifespan of textile products by being transferred to new owners [1,2,3]. Apparel reuse is an effective scheme for delaying landfill disposal and limiting environmental impact, but this approach alone cannot solve the rapidly increasing quantities of textile waste.

The high volume of textile products, their inferior quality, the costs of collection, shipping, selection, and disassembly, as well as the technical difficulty of separating by fibre category due to the high complexity of textile articles and the low added value of the materials derived, represent a technical and economic barrier that discourages the valorization of textile waste. The reduced costs of incineration and landfills further decrease recycling efforts, amplifying the negative environmental impact. [4,5,6].

Developments in recycling technologies for the recovery of textile waste are key to boosting recycling rates and converting these raw materials into cost-effective and economically feasible goods. Therefore, the ideal scenario is that textile waste is first reused and then passed through mechanical and/or chemical recycling processes to reach the lower limit of economic reliability of resulting fibres, polymers, and/ or oligomers. The newly recovered materials can be further processed into equivalent products. A substantial percentage of textile waste is represented by cotton and polyester, which are the most investigated materials in waste recovery studies. [7,8].

1.1. Recycled raw materials

Closed-loop recycling is when textile waste is transformed into products of the same type as the original products. In most cases, chemical recycling is more appropriate for this purpose, because by decomposition down to the monomer/oligomer level, the necessary quality can be provided to produce raw materials that can be transformed into products of the same or even higher value than the original recycling product. Achievement of this objective is limited by the current state of implementation at the industrial scale, the limited information on the environmental impact of the substances needed for chemical recycling, and the mixtures of elements in the textile articles that affect the degree of purity of the resulting polymers. [9].

When the recycled material has an inferior value (or quality) than the original product, is called "downcycling". Since the length of the constituent fibres is reduced through wear and tear, mechanical recycling of textile waste often results in products of inferior quality to the initial one. The reason for this is the limited recycling cycles of synthetic fibres (7-9 cycles) and cellulosic fibres (4-6 cycles), but additionally, the substantial number of chemicals (over 8000) used in textile processing that are found in recovered fibres [10,11]. At present, existing textile recycling routes are predominantly downcycling.

The closed-loop approach and the predominant nature of down recycling may not be a profitable option as it may introduce supplementary costs related to the collecting, transporting, sorting, chemical or mechanical treatment of textile waste, and the outcome will be unattractive from a qualitative and economic point of view. [12,13].

Open-loop recycling (also called cascading recycling) covers processes by which textile waste is transformed into products different from the original ones and even transferred to other applications [9]. From the perspective of energy conservation, it also includes incineration with recovery of heat or electricity, which is to be preferred to routing textile waste to landfills. The development and industrialization of new technologies, such as pyrolysis and gasification, for textile waste incineration are at an intermediate stage, and their economic feasibility has not yet been validated [5,14]. Regardless of the emissions of chemicals toxic to health, these textile waste-to-energy technologies play a significant role in volume reduction, mass reduction, and disinfection [15,17,18].

1.2. Virgin raw materials vs. recycled raw materials

Textile manufacturing is based on the use of virgin raw materials, which are at a critical stage of scarcity due to the depletion of natural resources. Accounting for the complete life cycle of textile products, from production to landfill of pre-and post-consumer articles at end-of-life, textile production accounts for 10% of carbon emissions, is the world's second most heavily polluting activity, and constitutes a comprehensive and challenging waste stream [19].

According to statistics, 70% of global textile fibre consumption is accounted for by synthetic fibres made from petroleum-based polymers such as nylon, acrylic, polyester, and polypropylene. From the farming and synthesis of fibres to the manufacture of yarns and fabrics, the textile industry uses considerable natural and energy resources, with a significant environmental footprint [20,21].

Textile waste flows include a pre-consumer waste (fibre and yarn waste, waste from the garment manufacturing operation, and downgraded textiles), post-consumer waste (end-of-life textiles), and industrial waste. For instance, the European Union (EU) annually generates about 5.8 million tonnes of post-consumer textile waste, only 25% of the overall volume is recycled into low-value products or by incineration, and the rest 75% is landfilled. [22].

The disposal of textile waste has damaging impacts on the environment and human health due to the degradation and generation of hazardous substances and greenhouse gases, including methane gas and ammonia. Furthermore, incineration piles for thermal or electrical energy recovery release organic substances including dioxins, heavy metals, acid gases, and dust particles, all of which are potentially dangerous to humans and the environment[24]. The major environmental impacts caused by the production of virgin fibres, the overall consumption of textile products, and the high percentage of disposal through storage or incineration confirm the benefits of recycling and extending the lifespan of textiles [20].

Moreover, the technologies that are available to turn textile waste into energy, through incineration, pyrolysis, and gasification, have performed an indispensable role in considerably reducing the mass and volume of waste, as well as in recovering energy from non-recyclable materials and in completely disinfecting them [15,16].

Europe has adopted several directives on waste management, treatment, and disposal, for instance, the Waste Framework Directive [24], the Landfill Directive [25], and the Waste Incineration Directive [26], which aim to guide EU countries toward recycling-friendly approaches by adapting waste management practices to sustainable ways, enhancing resource recovery and reducing landfill capacity expansion. Though legislative policy drivers are in place, socio-economic factors have been preventing the use of these directives, and landfilling of textile waste is still carried out.

2. METHODS FOR MODELLING RECYCLING IN LCA

2.1. Life cycle assessment of recycled textiles

A key element in assessing the recycling case is to quantify the economic viability as well as the environmental impact. The principal instrument for assessing environmental impact is the product Life Cycle Assessment. This evaluation is necessary to establish the magnitude of the impact of the proposed recycling method and its environmental advantages or disadvantages. In the course of our investigation, we found that life cycle assessment has been applied in over 40 studies analyzing the impact of textile waste recycling. Polyester is the most widely studied, and impact assessments on proposed recycling methods are not very numerous. As a result, there is a gap in studies exploring the limits of textile reuse and recycling, and the benefits of combining different types of reuse and recycling approaches [20, 27,28,29,30]. The scientific community, as we have seen, is strongly focused on finding feasible solutions for the recovery of textile waste. Quantifying the environmental impact of overall virgin fibre production and preserving the linear pattern of textile consumption through landfill disposal or incineration supports the advantage of extending the life of these materials through reuse, recycling, or transfer to other applications [20]. The development of recycling technologies for textile recovery and their industrial implementation is essential to ensure closed-loop processing of textile waste and to reach the aims of the circular economy [31].

The examples of these studies are numerous and go beyond the textile industry, as they are intended to be used in products incorporating agricultural, wood processing, and even construction waste, acting as a matrix or reinforcing agent. The growing amount of non-recycled textile waste makes it a precious resource that can successfully replace valuable raw materials traditionally used in building materials, thereby contributing to reducing the environmental burden. Changing the perception of textile waste and processing it as a secondary raw material, will significantly contribute to increasing its value.

LCA is especially relevant for the evaluation of new products/technologies, as it allows the environmental footprint to be studied or compared before it reaches the industrial application phase or is proposed as an alternative to existing technological solutions or products. [31].

Inventory analysis involves the systematic collection of the needed input data and the assessment of output data related to the life cycle stages of the product under investigation. These are categorised into input data, which relate to raw materials, energy and fuels, and output data, which measure emissions to water, soil and air. According to ISO 14040:2006 [32] and ISO 14044:2006 [33], at this stage of the evaluation, the calculation methods and procedures used should validate the input data used and assign characteristic data to each process in the reference stream according to the functional unit adopted.

The most widely used software packages dealing with life cycle analysis and assessment are GaBi Software (PE International Germany), SimaPro LCA (PreConsultants Netherlands), and openLCA (GreenDelta GmbH Germany). The basic step of an LCA study includes the definition of the raw material used to produce the product under analysis.

In the textile industry, LCA is used to identify potential environmental impacts at different stages of the life cycle of textile goods. Life cycle analysis is applied in several studies addressing the reuse and recycling of textile waste, highlighting the environmental benefits compared to incineration and landfill disposal.[20,30,33,34].

2.2. Modelling material recycling in LCA

The literature studies reveal many controversies regarding the modelling of recycling of used materials and LCA [35]. Several recycling modelling methods are applicable in LCA studies, depending on the purpose and the scope of the study. Ekvall [36] outlines a framework of environmental impact assesment method criteria, under the assumption that a technique is more effective if it is expected to improve the impact on the environment, or at least the impact per unit of output benefit.

2.2.1. Recommended methods for modelling recycling

As a result of the literature review, Table 1 describes most of the proposed methods for modelling recycling in LCA. These methods are suggested by important standards and guidelines.

Table 1
Methods for recycling

Method	Substitute name	Recommended
Simple cut-off	Recycled content approach	International EPD system PAS 2050 Greenhouse Gas Protocol
Cut-off with economic allocation	-	Dutch Handbook on LCA
Cut-off plus credit	Module D	ISO 21930:2017 EN 15804:2012+A2 + CEN/TR 16970:2016 EN16485:2014
Allocation to material losses	Closed-loop approximation 0/100 method End-of-life approach Recyclability substitution Value of scrap approach	ISO 14044:2006 + ISO TR 14049:2012 ISO 14067:2018 ISO 20915:2018 PAS 2050:2011 Greenhouse Gas Protocol WorldSteel Association International Stainless-Steel Forum
Allocation to virgin material use	100/0 method	-
50/50 methods	-	Nordic Guidelines on LCA Ekvall (2000)
Quality-adjusted 50/50 methods	UBA approach	German requirements on LCA of beverage packaging Allacker et al. (2017)
Circular Footprint Formula	PEF approach	Product Environmental Footprint Guide
Market price-based allocation	Open-loop procedure	ISO 14067:2018
Allocation at the point of substitution	APOS	Ecoinvent

The simple cutting method is the easiest technique to model recycling. The principle assumes that each product is allocated the environmental loads of the processes in that product's lifetime. The only difficulty consists in defining the boundary before, within, or after recycling the material between the life cycles. The cut-off method is advised by the International System for Environmental Product Declarations (EPD), which sets the boundary between life cycles as the point at which the material has the lowest market value [36]. The method offers positive incentives for the use of recycled materials, since the recycling has a lower environmental impact than the production of virgin materials.

The application of the "Cut-off with economic allocation" approach is much more complex than the simple cut-off method because economic allocation requires price data to be collected or calculated. However, the approach does not involve environmental data on processes that go outside the product life cycle.

The standards divide the lifecycle of a manufactured product into modules A-C and the results are reported separately for each module; a cradle-to-grave life cycle. The EPD covers all three modules A, B and C. Module D might incorporate the specific part of the recycling life cycle that corresponds to the life cycle in which the recycled material is processed.

Allocation to material losses is a closed-loop approach where the environmental loads of the recycling phases are assigned upstream; to the item that supplies the recyclable waste.

Allocation to virgin material use illustrates the assumption that materials extracted will inevitably end up as waste. This approach necessitates data about the final disposal of the recycled material after use in the investigated product.

The 50/50 method is a closed-loop approach where the flow is determined as the average of the input and output of recycled materials on the system boundaries of the life cycle.

Quality-adjusted 50/50 methods reflect the approach that the more a material deteriorates, the faster it will have to be discarded and substituted with virgin material.

The Circular Footprint Formula stands out for the balance between supply and demand for recycled material on the marketplace.

Market price-based allocation mitigates that the production of raw/virgin material should be divided between the product which includes the virgin materials and the product where the material is discarded.

Allocation at the point of substitution is created to manage the waste that can be transformed into new products and is a method in the Ecoinvent database.

All these methods have different approaches due to the allocation method in material recycling. This refers to the way the recycling activities are allocated.

3. CONCLUSIONS

This paper briefly presents the allocation methods for analyzing the environmental impact of recycled material using the LCA methodology. The result of the LCA study can be very different due to the input data allocation. The most common approach in the literature assumes that recycled raw material is equivalent to virgin raw material, which involves adopting the cut-off scenario allocation in carbon footprint impact.

Most of the proposed methods for modelling recycling in LCA, i.e. Cut-off with economic allocation, Allocation to material losses, Cut-off plus credit, Allocation to virgin material use, Quality-adjusted 50/50 methods, 50/50 methods, Circular Footprint Formula, Market price-based allocation and Allocation at the point of substitution have different allocation regarding material recycling. Thus, depending on the type of the product analyzed and the purpose of the analysis it is indicated to choose one of the approaches recommended to the international standards and guidelines.

This requires that a successful method must be feasible and where possible user friendly. The outputs must be sufficiently reliable, comprehensible reportable, and considered relevant to policymakers. In addition, the method chosen must highlight the environmental impact of the recycling material.

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EMBRACING 3D PRINTING AND MODELLING FOR A SUSTAINABLE FUTURE IN FASHION

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***Abstract**. Currently, the production process in the fashion industry has become very energy-intensive and wasteful. This time-consuming process has resulted in far too much waste of resources, with a negative environmental impact on future generations. Transforming this production process into a more efficient and sustainable one through digital technology has become an urgent goal of the textile industry. Changing how clothes are made will also contribute significantly to sustainable and digital progress in apparel production. For example, 3D modelling, virtual prototyping and digital sampling are replacing the traditional process of modifying patterns and samples to speed up garment development and reduce production costs. With increasing awareness of the need for sustainability, these technological tools (e.g., 3D modelling environment) have become essential for designers and engineers. The 3D-printed fashion industry continues to develop and grow. This article studies 3D fashion creation and delivery technologies: pattern making, simulation and printing. Techniques and systems for 3D modelling and garment simulation, software for processing and modelling 3D objects, and 3D printing are reviewed and implemented. The results are a 3D avatar with custom garments, which are tested and 3D printed after the design process is complete. The virtual customisation of garments is a sustainable option using new technologies, which also allows for the expression of creative freedom. For example, digital fashion garments and accessories can be easily adapted to meet needs and desires. Creating personalised garment elements can involve a complex mix of several complementary processes and materials: handcraft, embroidery, 3D printing and a different mix of conventional and unconventional materials. Physical properties and material durability are also explored in this article. The literature review methodology presents further demonstration cases to show the adaptability and customisation of the 3D printing approach for the fashion industry. Digitisation also allows for a high range of logistic flexibility. Using digital models expands the possibilities for research, development, design and testing innovative techniques such as the multiple mesh system.*

***Keywords:** 3D technology, digital fashion, 2D/3D design, digital transformation, sustainability.*

1. INTRODUCTION

As technology continues to advance, our dependence on it grows stronger [1]. Three-dimensional printing (3DP) is a prime example of such technological progress opening up a world of novel creative prospects, gradually infiltrating various industries, including architecture [2], healthcare [3], aerospace [4], electronics [5], energy [6] and beyond.

Based on Industry 4.0's pillars, developing technology will improve the clothing industry's future. This will result in creative and sustainable clothing design [7, 8].

3D printing is revolutionising the twenty-first-century fashion industry, leading to significant advancements such as more eco-friendly, personalised clothing and accessories, simplified logistics and reduced costs, greater creativity, and collaboration among diverse specialists [9]. 3D printing, also known as additive manufacturing (AM), is a fast way to produce prototypes. It involves sending a computer file or design to a printer that can build 3D objects by adding layers of material.

Fused deposition modelling (FDM) is a standard method of creating simple prototypes and functional small-sized parts in the engineering of AM processes. This method is ideal for fast design iterations and efficient manufacturing. FDM is a 3D printing method that works by squeezing melted thermoplastic polymers that come in filament form. The mixture paste is then deposited line by line to create a layer. This layering process is repeated multiple times to build up the final product. In the textile industry, the most common filaments used are thermoplastic polyurethane (TPU) and acrylonitrile butadiene styrene (ABS) [10]. The production of parts in FDM is divided into three steps: pre-production, production and post-production. Printing parameters such as infill thickness, pattern design, layer thickness, temperature, printing angle, speed, and model orientation have a significant impact on the product's overall quality.

3D printing in fashion lets designers draw inspiration from the art and high-end fashion industries in order to attend exhibitions and shows and create intricate and multi-faceted designs [11]. They are now recognising the potential of this developing technology and considering how they can use it on a larger scale for customized design solutions [12]. User-defined 3D printing designs enable consumers to conveniently access 3D models of required products online. Such products can be directly selected and printed using a home printer.

For 2023, 80 additive manufacturing experts have forecast trends in 3D printing, concluding that adoption of this industrial technology will accelerate, especially with an increase in the number of end-use applications validated under the circular economy model with efficient, recyclable and biodegradable materials. In the future, 3D printing will continue to see an acceleration in the synergy between materials science, manufacturing, and technology, revealing new prospects for innovation that were not yet considered [13, 14].

Danit Peleg is a fashion designer who uses 3D printing technology in her work. She gained recognition for being the first designer to create an entire collection using 3D printers at home [15].

New players like Stratasys have a portfolio of industrial-grade 3D printers and cover the entire value chain from rapid prototyping to mass production of end-use parts. In the Polyjet series printers, there are two models: J850™ TechStyle™ - which facilitates 3D printing on flexible and flat substrates such as fabrics, carbon fibres, elastic polymers, mesh, canvas and more, and FabriX Kit, which offers full-colour, multi-material capabilities for designs that can be printed directly onto fabrics, garments, footwear and luxury accessories, delivering results not possible with traditional methods [16]. Ada Hefetz has launched a new line of wedding dresses made using additive manufacturing, namely three garments that combine traditional design with new technologies [17]. Designer Karim Rashid, renowned as the "Prince of Plastic," worked with Stratasys technology to create the Digi dress as a constituent of the Reflection Collection. The 3D printed design embodies his iconic style of art graphics and geometry [18],[19]. The tiny hues and light filtering of butterfly and insect wings inspire Julia Koerner for her Chro-Morpho Collection. The polymers were directly added to the pieces. Jasna Rokegem made the Trypophilia Collection - a clothing sequence that mirrors emotions through the potential of 3D printing onto fabric with the J850 TechStyle printer from Stratasys. Ganit Goldstein is a 3D designer and textile researcher who has pushed the boundaries of fashion by using the Stratasys 3D printer to create her GnoMon Collection. As part of the Reflection Collection by Stratasys, fashion designer Lana Dumitru and architect Vlad Tenu created 3D dresses with traditional Romanian patterns for contemporary living. FORÆVA's embroidery crosses cultures and showcases the power of storytelling to connect people. The 3D-printed items uncover concealed messages when examined closely [20].

With this printing technology, Stratasys is revolutionizing how designers and engineers think about 3D printing and opening up new possibilities for creativity and innovation, as presented in the collection of collaborations with designers.

Lilach Porge concentrates on blending technology with fashion. The range uses sustainable materials and features 3D-printed designs created by a robotic arm using Random, Accurate and Large-Scale techniques [21].

Most 3D garments and textiles are produced utilising a Fused Deposition Modelling (FDM) printer. This process entails depositing and melting thermoplastic filaments. Researchers developed a 3D printed garment design software using flat patterns and design motifs to allow fast and easy generation of a 3D printed garment [22].

3D printing has an incredibly diverse range of applications for the textile industry. From creating shape technique, this innovative approach to design involves generating algorithms in Grasshopper that produce curve patterns that, when under tension, transform into structures through fabric-like materials [23] via under extrusion DefeXtiles - 3D printing quasi-woven [24, 25].

Sara Alvarez has accomplished some achievements in producing textile-like substances using 3D printing. Though they are not the same, they possess comparable traits that distinguish them as exclusive and valuable. The simplest method is chainmail, where many tiny individual links are joined to form a relatively rigid material. Alternatively, with careful modelling or G-code, fabric-like patterns on a flexible material, resulting in a sheet that resembles fabric can be produced. Finally, the infill technique uses code embedded in a slicer to create a design that can be 3D-printed to fabricate a textile-like material by extracting the upper and lower layers of the print [26].

This paper aims to assimilate the experiences of fashion designers who use the digital simulation of garments and accessories with 3D design technology and parametric design. The paper's key points involve practical examples of how innovative technologies such as modelling and 3D printing change how textile designers and engineers think of garments to meet new consumer needs.

2. EXPERIMENTAL PART

3D modelling, virtual prototyping and digital sampling are replacing the traditional process of modifying patterns and samples to speed up garment development and reduce production costs. With increasing awareness of the need for sustainability, these technological tools (e.g., 3D modelling environment) have become essential for designers and engineers.

The 3D-printed fashion industry continues to develop and grow. This article studies 3D fashion creation and delivery technologies: pattern making, simulation and printing. Techniques and systems for 3D modelling and garment simulation, software for processing and modelling 3D objects, and 3D printing are reviewed and implemented.

We used an organic nature-inspired complex design model with the goal of 3D printing it on textile fabric using various TPU filaments. In our design process, we created organic Voronoi-like shapes resembling crochet using algorithmic design (grasshopper for Rhino) to produce a piece blending tradition and innovation. The model is presented in Figure 1. 3D modelling in Rhino and Grasshopper enables fashion design to use generative processes that produce complex models through the parametric method. Rhino creates NURBS solid models, which, for 3D printing, must be exported as a solid model, most commonly stereographic lithography (.stl), and converted by the slicer software into G-code.

Models can also be created using other CAD software and/or shared on model-sharing platforms such as Thingiverse or MyMiniFactory. Geometric shapes, particularly those with gaps that allow for flexibility, are ideal for creating viable fabric designs.

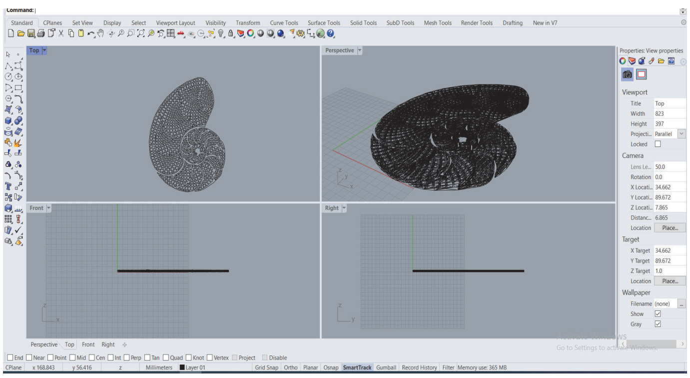

Figure 1. Modelling process of organic model in Rhinoceros 3D: Rhino

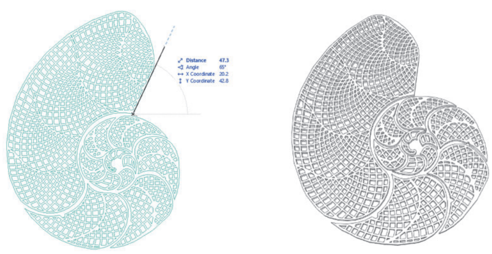

Figure 2. Organic model

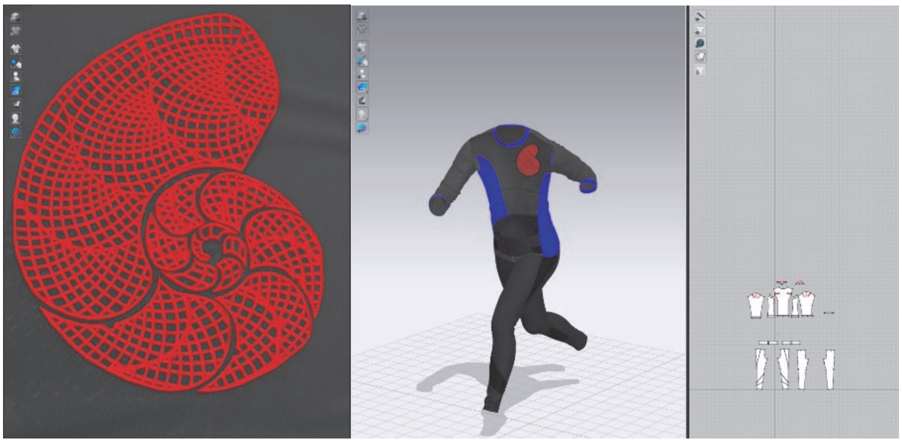

Figure 3. Simulation of organic motif on garment in Clo3D

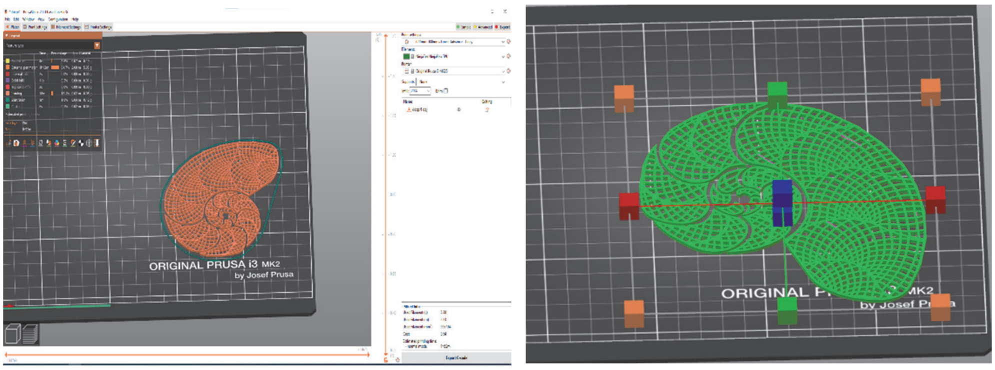

Figure 4. Preparing a model for print preview on Prusa I3 Mk2.

The study explores the variable parameters and techniques associated with 3D printing on fabric in order to achieve a durable and sustainable result when printing complex models using flexible thermoplastics such as TPU. We chose the TPU family of thermoplastics as it is already being used in the clothing industry, with previous studies showing that TPU elements can be used in joining clothing pieces made from low-elasticity chiffon fabrics to increase wearing comfort. [27, 28].

TPU is known for its solid and flexible properties, as written in Table 1, making it a versatile substance that can be used in various medical and industrial applications [29]. It has an exceptional capacity to withstand tears, chemicals, and abrasion and is compatible with skin. TPU boasts remarkable elongation resistance to ozone, low temperatures, oxygen, oil, fuels, and fungus. It also showcases antimicrobial attributes, soft elasticity, and excellent bending and tensile strength. Its long-term deformation rate is low, making it an ideal material choice.

Table 1
Properties of TPU (NinjaFlex).

Properties	Values
Density (kg/m^3)	1040
Glass transition temperature (Tg) (o ^{C})	-35
Tensile strength (MPa)	26
Melt processing temperature (o ^{C})	216
Izod impact strength (kJ/m^2)	4.2
Shore hardness (A)	85
Elongation at break %	660

3. METHODOLOGY AND RESULTS

We simulated fitting and positioning using a 3D avatar with custom garments, which are tested and 3D printed after the design process is totally complete. The virtual customisation of garments is a sustainable option using new technologies, which also allows for the expression of creative freedom. For example,

digital fashion garments and accessories can be easily adapted to meet needs and desires. Creating personalised garment elements can involve a complex mix of several complementary processes and materials: handcraft, embroidery, 3D printing and a different mix of conventional and unconventional materials.
We tested adhesion with two significant variables in mind: print speed and support material, as illustrated in Figure 6.

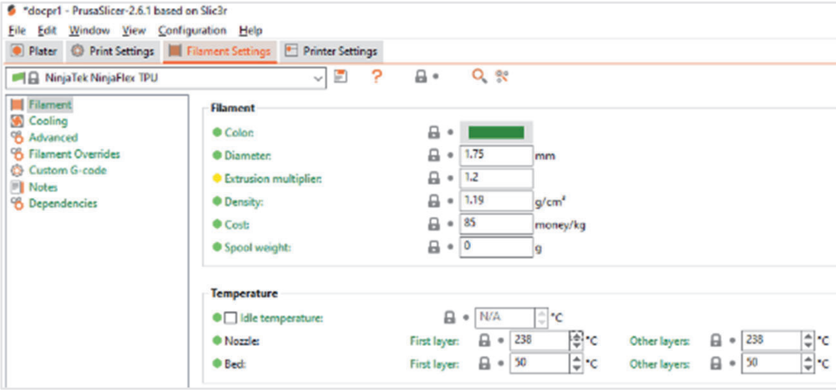

Figure 5. Filament settings

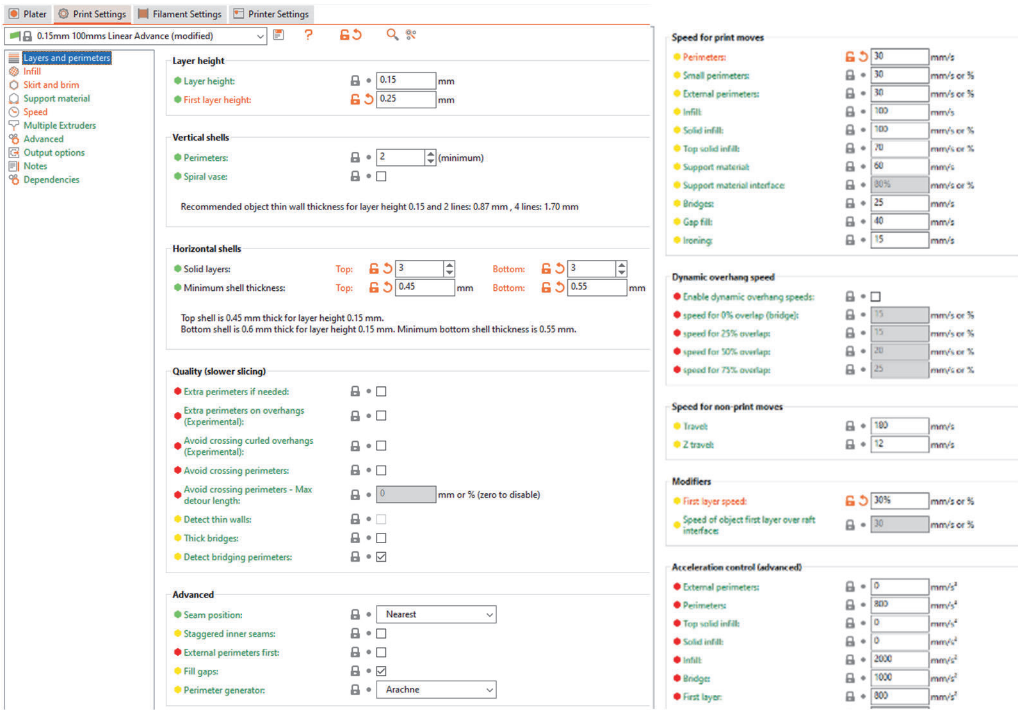

Figure 6. Print settings

In order to conclude which techniques, materials and parameters are the most suitable for integrating printed decorative pieces on clothing, we tested flexible materials, generic TPU and Ninja-flex in an array of scenarios that had variable printing temperatures, speeds and material application techniques.

Our main goal was to ascertain the viability of printing thin (<3mm) decorations or applications directly on the fabric while judging the reliability of application results, resistance to wear and tear, and size and complexity of models.

For Ninja-flex, there were a series of test pieces with dimensions ranging from 200 cm^2 to 80 cm^2. We observed that the size of the objects and layer height were far less impactful than any of the other printing parameters, such as speed, infill density or geometry of application. This is due to the high flexibility of the material, which favours adhesion retention.

When it came to this very flexible thermoplastic, the level of detail in the model also had very little impact when it came to the viability of the print and application, further confirming our expectations that 3D printing has a large and up-and-coming role to play in the near future of the clothing industry.

A third noteworthy conclusion was that for Ninja-flex, in particular, a high printing speed led to poor adhesion and applications coming apart during printing due to the lack of rigidity of the initial bond. These effects were far diminished when printing Ninja-flex on a rigid print bed with common adhesion solutions (glass+glue/textured print bed/ painter's tape, etc.), even with speeds of 30mm/s on the initial layer. In our fabric tests, we went with speeds between 5mm/s and 20mm/s with varying results. When exceeding 20mm/s for the initial layer, the adhesion was notably poor, leading to a scraped sample.

When it came to the textile materials, we printed on cotton, synthetic and fibreglass mesh. The two most impactful factors for adhesion were the tightness of the weave and the roughness of the finish. For slicker fabrics, adhesion was low, with very little resistance to wear and tear.

Synthetic fabrics yielded variable results due to the temperature of the print, leading to warping and colouration/discolouration. Where the melting point of the materials was lower, a better bond was formed between the thermoplastic (Ninja-flex) and the synthetic fabric. In the case of composite materials (natural fibre and synthetic), because the natural fibre was in a high proportion, simple adhesion through heat moulding was poor.

We tried a mixed technique, with printing the first 1-2 layers directly on the printer bed and then interlacing a thin fabric (tulle, knitted mesh, etc.). The only instance where results were favourable was when we used a very thin mesh with large gaps so that the thermoplastic mostly adhered to itself, trapping the mesh fabric within.

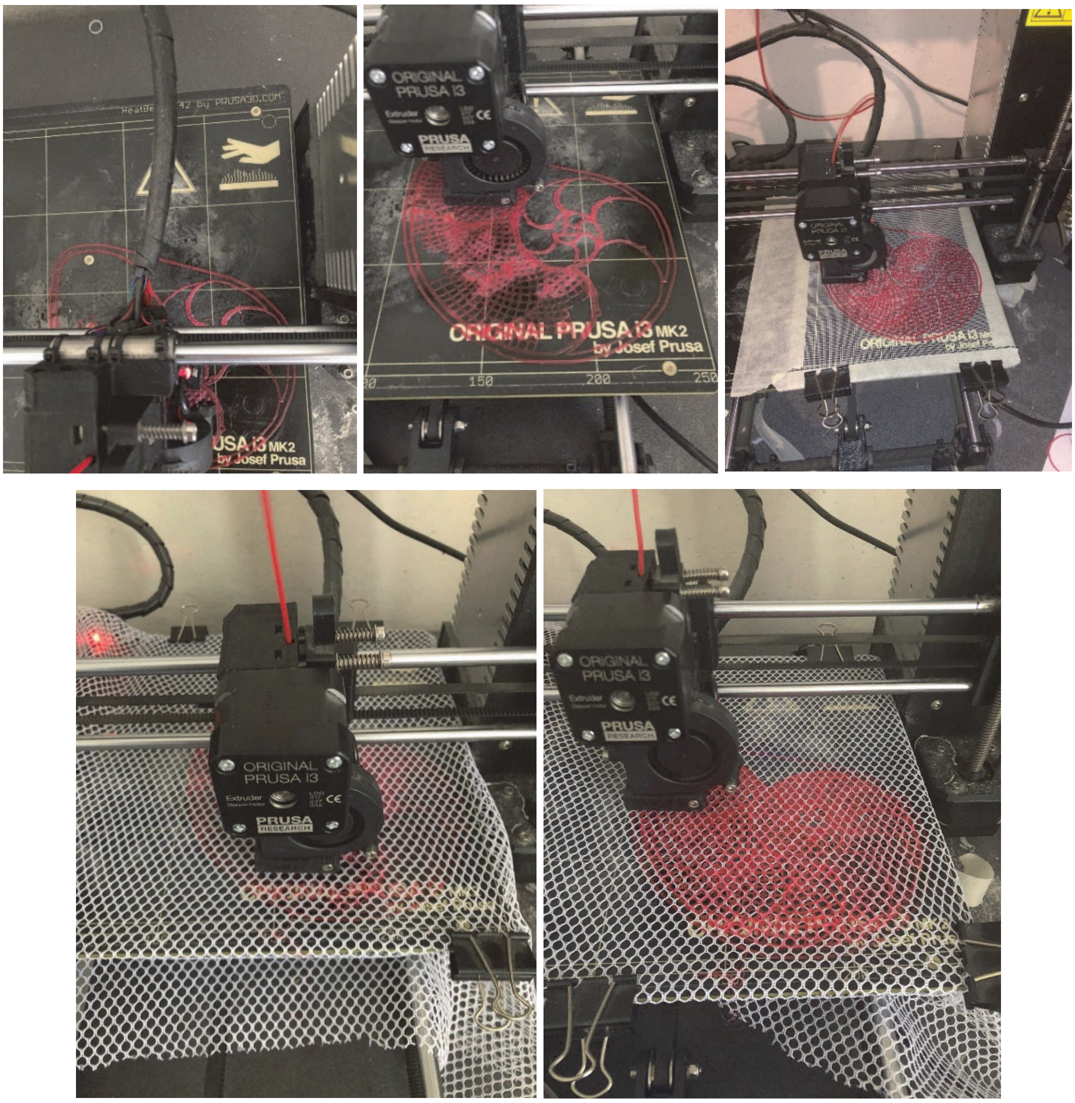

Figure 7. Varying speeds and adhesions techniques in progress

We had similar results when printing applications with TPU, with the distinction that it fared better with higher print speeds, but due to being less flexible than Ninja-flex, adhesion through direct heat application suffered, especially when printing larger objects with fewer joints. This is why, in our further testing of materials, we will assess the viability of fabric and plastic adhesives for thermoplastics with low flexibility and models with large planar surfaces.

We also tested the new feature released by Prusa with their Slicer in the 2.6.1 version, ironing, which uses the hotter to flatten the final layer of the print after it is deposited, thus obtaining a smooth and compact finish. Using ironing fixed potential exfoliation issues that sometimes occurred in curved surfaces and made the ornamental objects more aesthetic overall. This was at the cost of approximately 25% of the overall print time for most of our test pieces because of the general geometry of flat planar objects. When using ironing for taller ornaments, ironing only constituted 10-12% of total print time.

4. CONCLUSIONS

Our conclusions are as follows:

- 3D printing and modelling proved themselves to be indispensable tools for designing and fabricating models and objects with a significant degree of complexity (organic patterns, geometric lattices, articulated tailored applications custom fit on anthropomorphic models, etc.). We expect their impact on the clothing industry to increase exponentially in the near future. Moreover, parametric design and 3D printing make it very viable to have individually customisable decorations and applications with near zero waste when it comes to fitting.
- Flexible thermoplastics such as TPU and Ninja-flex yield better results when printed on fabrics with lower weave density and higher synthetic content. Natural materials require specific additional steps or techniques to obtain a durable result.
- Print speed is a parameter directly linked to layer adhesion and, thus, is limited by printing directly on fabric (speeds <30mm/s). If we were to 3D print traditionally and glue the fabricated design pieces to the material, it would be less of a limiting factor.
- 3D printing has the potential to greatly benefit the fashion industry by decreasing waste and supporting sustainable practices. By enabling the creation of products on demand and making use of environmentally friendly materials, 3D printing presents a more eco-conscious approach to fashion production.

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SECOND LIFE OF A TEXTILE MULTI-COMPONENT WASTE - REVIEW

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Abstract. *Recycling with components sorting is one of the options to give a second life to textile waste when waste is not the proper word, actually because, for that segment, waste is a source of the material. This paper deals with an overview of people's behaviour in reuse and recycle principles, possibilities for obtaining textile waste, and recycling options with examples from current reality. Mostly, all clothes, especially technical clothing such as protective clothing, sport barrier clothes, technical textiles with semipermeable layers, etc., cannot easily decompose into a single raw component, see Figure 1. People decide to finish using textiles for reasons of season, fashion, damage, and individual preference. They give clothing for second use when cautious about the environment and society. The legislation makes special handling of such waste necessary when returning to the source. Only companies or non-profit organisations can manage the waste; even governments outsource to them.*

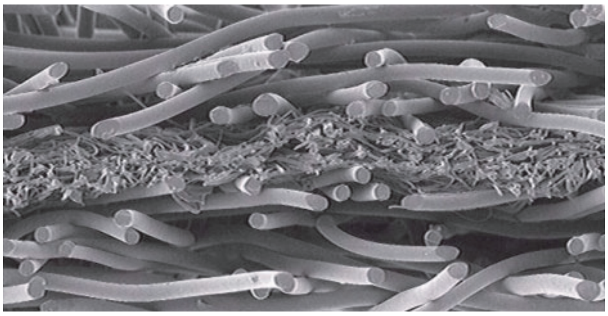

Figure 1. Example of the composition from 3 layers and laminated in a one-plane fabric

Some visions are pointed out, too, when their affordability and realisation are in the phases of testing with potential. One example is fully recyclable fibres PLA used to create an entire clothing product to follow the fibre-to-fibre concept. Such a company needs responsible customers who do not throw clothes out but return them to the company after they finish using them. Until visions turn to mass reality, we are referred to recycling at the levels allowed by nowadays technology as upcycling when creating new products, using another way as cleaning textiles, cutting and chopping for pieces, and composing nonwoven structures or composite layers, using insulation materials against sound, heat or cold; decompose for energy and more. The perfect recycling of polymers should decompose to the level of monomers or polymers and spin again.

Keywords: *sustainability, textile multi-component waste, recycling, sorting, reusing*

1. INTRODUCTION

Recycling is not something invented in the last 20 years but is a process of ideal use of raw materials, which has been applied by human civilisation for a long time, but it is a high priority to be taken to reduce the amount of waste generated and improve overall waste management processes and programs. The main waste hierarchy consists of 3 R's as follows [1]:

- ✓ Reduce
- ✓ Reuse
- ✓ Recycle

The popular prefix re- is used to expand the possibilities as repair, re-wear, resold, repurposed, and remake in circular economy behaviour. Providing proper and approved information is a task nowadays when information is attacking us and our emotions, for the EU acts The European Environment Agency (EEA), an agency of the European Union, whose task is to provide sound, independent information on the environment [1].

With approximately 800 containers for used clothes, the company must effectively recycle around 4 tons of textiles. Aside from that, there are all well-sorted textiles and shoes for second-hand sale/charity and cloths for cleaning in the industry. Those four tons are problematically sortable materials only. That shows the importance of effective solutions for high volumes of non-sortable clothes.

2. REUSING AND TEXTILE COLLECTION CONCEPTS

Reusing is defined as using again, especially in a different way or after reclaiming or reprocessing [2]. Reusing creates opportunities for the creativity of individuals and allows them to get involved when the integrity of the fabric is not completely dissolved. The study involved more than 500 respondents of all ages and found that 45% passed their clothes to friends and relatives, 18% repaired and redecorated their clothes for the second life, and 24% donated them. Only about 4% of respondents throw their clothes into the trash bin, which is rather positive behaviour, as found in this Slovenian study by Žurga and Col. [3]. Reusing cannot be divided from the textile collection and sorting. Sorting challenges are described in the next chapter.

The charity concept for the second life of used clothes considers that the economic aspect needs no changes to the clothing style in the second use of collected clothes. Collection and resell take local or mass collections without exceptions since the donation is unlimited. Charity can be organised by non-profit organisers or producers of clothes who care about the public opinion of the customers. The well-organised and publicly known concept is run by H&M Group when their stores accept any preloved clothes and textiles for recirculation and recycling [4], Diakonie Broumov [5], and Planet Aid [6].

Non-profit groups organise the collecting and transporting of used clothing as a support to the community of the region. Some of them are founded by local government; some are formed as a movement of the people like ReUse from Houston in Texas, who fund from those partners to support their infrastructures, administration boards, resources, philanthropy, and job opportunities [7].

Awareness about the second life of textiles is also necessary to prevent brand misuse problems. De-labelling or de-branding technologies that might be utilised for end-of-life corporate wear were reviewed by WRAP, which is a climate action NGO working mostly in the UK and limited not only to textiles [8]. Their activity also turns to the buyers with Love Your Clothes action [9] to educate the public and retailers with their Retailer clothing take-back guide [10].

UsedFULLY® Textile Reuse Programme from Wellington, NZ [11] provides onshore solutions for unwanted clothing and textiles to companies and individuals in the region. The complexity of their offer is because of the profit organisation with employees where being a member opens the range of the information collected by the specialist in the field. The potential for more companies is still huge in this industry part. Another example of the non-profit government platform in Flanders giving tips for the circular use of textiles is Close The Loop, which shows best practice examples [12]. Honk Kong [13] SgT, The Textile Quality Experts, is an independent service provider offering, for example, Green Claim Services and Validation of recycled products. Such a certification is important for the producers who declare their environmentally friendly products.

Regional associations allow a higher impact on legal actions and spread information widely, for example, Nordic cooperation, which involves Denmark, Finland, Iceland, Norway, Sweden, the Faroe Islands, Greenland and Åland with advantageous service in funding sustainable projects [14]. Information was given by other movements, such as Recycle Coach from Toronto, Canada [15, p. 3], and government information was given to the citizens as the Department of Energy and Environmental Protection in Connecticut, USA [16].

Textile platforms like Fibre2fashion [17] provide specialised information in a marketplace serving all textile, garment, and fashion industry segments. Information is given in various ways by key news agents CNN [18], producers of recycled materials [19], materials from non-traditional plants such as bananas [20] and orange [21] or materials easy to recycle into the fibre-to-fibre concepts such as PLA fibres [22]. Euratex advises and assists [23] with their ReHubs [24] initiative plans to pursue fibre-to-fibre recycling for 2.5 million tons of textile waste by 2030.

Textile SWAP – share of the clothing, how much you give, you can take as a living philosophy [25]. These special shear actions are based on no money exchange of the clothes. Small local groups are making a difference locally, and big organised events promote action to the majority in the cities so enthusiastic people can be involved and attract people who want to save their money, which is not bad either.

Consignment is an arrangement in which goods are left in the possession of an authorised third party to sell. Typically, the consignor receives a percentage of the revenue from the sale (sometimes a very large percentage) through a commission [26]. Some consignment sales are done online, too. Market-based on complete online communication between people who offer and buy or donate used clothes is nowadays an increasing field. For example, reGAIN [27], Vinted [28], Thrift+ [29], Reskinned Clothing [30] and more. People must bear the shipping process but know that 100% of their given clothes will be reused and will not go straight to the landfill.

Designers use second-hand textiles for production; examples can be found in the Designers platform information [31]. Also, the Internet contains tutorials on how to reuse clothing for other objects, such as DIY websites or workshops. They are run by individuals or companies who would like to guide and act responsibly as a conscious source user, for example, Veolia in Nottinghamshire, UK [32]. Designers can work on their design products with children in school or leisure seminars workshops, which is good for educating children on creative work and being aware of textiles—production for children in a low number of original products, toys, pillows, etc. A Very nice summary is given by Van't Hul, which techniques children can handle [33] or a slightly sophisticated approach by textile designers [34]. There is no border in the creativity to use textiles and other kinds of waste to produce original pieces; the second life of textiles is very different.

3. SORTING EXAMPLES

Diakonie Broumov is a non-profit organisation that acts as a charity for people in need. The charity gave the following information during an excursion to a place. Sorting of textiles begins with the collection and transport to the sorting fields. There is no possibility to sort by automation only. Handwork by a skilled and trained operator is necessary. Imagine operators cannot wear gloves because the fabric handle is important for the sorting.

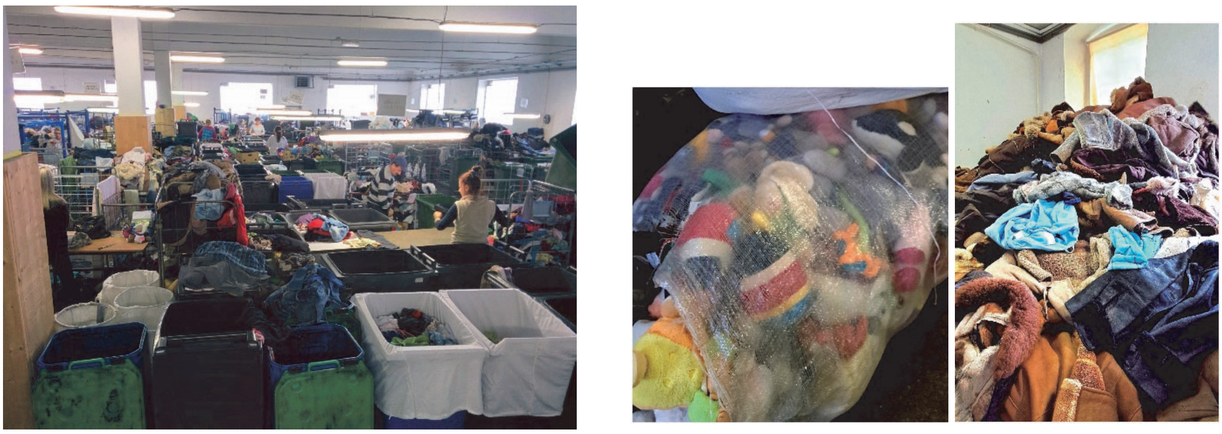

Figure 2. Sorting field [35]

Automation can only help the operator transport textiles to each person as a line-feeding mechanism. Such a device can help with rough sorting. People who want to give their used textiles and clothes to charity should be prepared. Companies prefer to separate clothes in plastic bags to prevent dirt from devaluing clothes. Shoes should be separated in plastic bags in pairs together. There is nothing more sad than finding a single shoe in a mess. Nobody has time to find one shoe to another when delivery comes.

Companies and charities sorting textiles and clothes must have legal permission to deal with the waste. They are handling this to use what was wasted to return as a new product and use it as a source. Also, profit organisations are working in this field and trying to adapt as much material as possible into usable subjects.

One example from all of the competing companies is Dimatex [36]. Their products are usually cleaning cloths and composite profiles with textile filling used as a component in various fields where exact material history is unnecessary. That is the crucial point of the second use of all sorted materials. Sorting costs money for the manpower of the operator, which is rather expensive, of course. On the other hand, textiles have to be sorted out effectively and as much as possible to be used in special products.

Figure 3. Sorting in Dimatex company [36]

Now, the non-polymer parts of textiles are very unpleasant contaminants for us, which makes the recycling process complicated. A typical example is dyes, which are part of almost every clothing fabric. It is one of the key problems of real textile recycling - how do we verify that prohibited dyes are not part of the recycled material here and now? Testing every textile piece entering recycling for the content of today's banned dyes is impossible. The current labelling of textiles is sophisticated and mandatory for most textiles, but from the point of view of recycling, its current form is difficult to use [37]. Textile composition marking technologies are possible but always have certain limitations. For example, it is possible to implement chips carrying the necessary information into textiles, but they are relatively expensive, difficult to implement without affecting their properties, and ultimately complicate the recycling process by their presence [38].

Only sorting automation without the necessity of human labour is offered by spectral analysis by near-infrared spectroscopy (NIR spectroscopy) of the textiles that are specific for all raw fibre materials [39], [40]. Commercially, you can find SPECIM [41], which is based on the wavelengths and reflectance of single fibres such as acryl, polyester, linen, alpaca wool, etc. and defines hyperspectral technology, which allows the distinction between synthetic, plant-based and animal-based fibres. Fast use for the public is promised by trinamiX [42] or NIRONE Scanner [43] by using the app on individual mobile phones. We will wait to see if this way will evolve into mass use for individual customers.

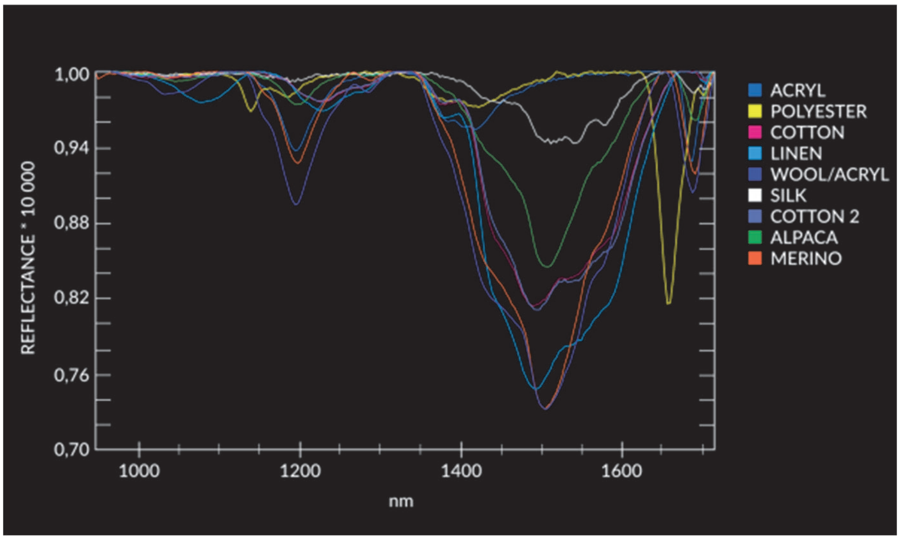

Figure 4. Identification of the chemical composition of the inspected materials [41]

Only one facility now promises two accurate methods for mass sorting using near-infrared and visual spectroscopy (NIR/VIS). Siptex from Sweden [44] sorts textile waste by fibre type and colour. The textiles are illuminated, and the light is reflected differently depending on the material. Sensors detect and calculate the type of fibre. Compressed air blows the fabric to end up in the right container. The plant can be programmed to sort out three different flows simultaneously [44].

It is unlikely we do not see any numbers behind the sorting by manpower and sorting by NIR/VIS technique to compare costs, but both of them must profit to survive the company. There would be different costs for companies from Sweden, where Siptex runs, than in African countries, where textile sorting is also necessary. An educated operator is crucial; sorting lines with a semiautomatic system can act well for some time.

4. HOW TO ORGANISE SMALL SWAP

SWAP can unite several people managed by individual organisers or with a helping hand. No one can expect income from the voluntary work. Organisers are starting enthusiastically, and only a minority can grow. But also, the small SWAP matters. Activities like that help to include sustainability in our daily routine. Participation in SWAP is limited by social outlook (some people consider buying second-hand clothing a social stigma) and concerns about quality, and only education can help.

Motivation for participation/organisation [45], [46], [25]:

- environmental (to be environmentally responsible),
- economic (to add an original piece of clothing to my wardrobe),
- and social (to send my clothes on, to give them a "second life", to give joy, to do a good deed, to strengthen community life).

What needs to be prepared for the organisation of SWAP [47], [48]: Find the venue; Determine the focus and limitation of the SWAP; Prepare how the clothes will be displayed; Plan what to do with the surplus; Prepare an invitation for your target group, publish the rules; Find voluntary helpers.

The venue is important in size according to how many people the organiser expects to invite. The small room is fine for five friends who will share. In case of public invitations, hotels or restaurants can offer free rooms when they will profit from consumption. Outdoor activities are very good in gardens or parks, but do not forget to ask the town hall permission to use public areas. Summer and spring are perfect for such an open-air SWAP. Many SWAP actions started as a part of a fair or festival where locals could hear music or find small refreshments [47], [48].

Every organiser has to expect some clothes to remain, and plans must be made about who can benefit from them (e.g., local foundations such as children's homes, various social associations, and dog shelters). Small SWAP can be used from one day for the next event. It is better to ask local sorting companies for big events if no other way is possible [47], [48].

Figure 5. SWAP party [25]

5. CONCLUSION

Waste reduction is a key task for everybody who cares for the environment; even small actions can help. The paper summarises the activities and organisations giving information or collecting the textiles. Two examples were then described closely. One classical sorting organisation work on the redefinition of textile waste and turns it into a source in different ways of use. The second example is how an individual can do or be part of it. A SWAP of clothes is how a single person can reduce the amount of clothes even before they are defined as waste. The purpose of the use did not change. We cannot expect one universal technology for all materials to be recycled or reused without mass losses nowadays, but with proper sorting and recycling, we can start closing the gap between linear consumption and the circular use of sources, preferably from natural renewable sources. That is what we owe to the planet and for our future.

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SUSTAINABLE HORIZONS: EXPLORING TECHNICAL TEXTILES AND ENVIRONMENTAL RESPONSIBILITY

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Abstract. *Technical textiles have evolved into indispensable materials with multifunctional capabilities, finding application across diverse sectors such as healthcare, automotive, and concerns regarding their environmental footprint. This state-of-the-art review critically examines the intersection of technical textiles and sustainability, evaluating advancements, persistent challenges, and future trajectories. This paper explores the intersection of technical textiles and sustainability, emphasizing developments, research methods, and implications for the field. The study reviews the current state of research in sustainable technical textiles, considering materials, manufacturing processes, and applications. It highlights the growing importance of sustainable materials like recycled fibers and bio-based materials, alongside eco-friendly manufacturing methods such as circular economy principles which play a pivotal role in advancing sustainability in this domain. A comprehensive review methodology has been employed, synthesizing information from reviewed literature and industry reports. This approach provides a holistic view of the evolving landscape of sustainable technical textiles. One of the pivotal dimensions of sustainable technical textiles lies in the materials themselves. Recycled fibers, sourced from PET bottles and post-consumer textile waste, have gained prominence, spurred by breakthroughs in recycling technologies. Bio-based materials, including fibers and polymers, represent an eco-conscious alternative. Smart textiles, integrated with materials like shape memory alloys and conductive polymers, are not only enhancing functionality but also contributing to energy efficiency. This review discusses barriers, including cost constraints and technological limitations emphasizing the significant strides made in sustainable technical textiles, spanning materials, manufacturing, and applications. Notably, it discusses how recycled fibers, bio-based materials, and smart textiles contribute to sustainability objectives. The shift towards eco-friendly manufacturing processes and circular economy principles is reshaping the industry. This paper provides a contribution to the field by giving a complete overview of sustainable technical textiles, identifying key trends, challenges and opportunities. It is a useful resource for researchers, practitioners and policy makers who want to foster sustainability in the textile industry. Future research directions should focus on addressing barriers, fostering innovation, and advancing sustainability metrics for technical textiles, to fully harness the transformative potential of technical textiles in forging a sustainable environment and paving the way for a more environmentally responsible future.*

Keywords: *sustainable materials, sustainable manufacturing, environmental impact assessment, circular economy, smart textiles.*

1. INTRODUCTION

Technical textiles have evolved into indispensable materials with multifunctional capabilities, finding application across varied sectors such as healthcare, automotive, and with various concerns regarding their environmental footprint. As the 21st century unfolds, the textile industry is witnessing a paradigm shift where the traditional perception of textiles as mere commodities has transformed into a recognition of their multifaceted potential [1]. These innovative textiles, often engineered to possess unique properties and functionalities, are commonly referred to as "technical textiles" and encompass a wide spectrum of applications.

One of the most pressing challenges of our time is the urgent need for sustainability across all industries [2]. The textile sector, being one of the largest industrial polluters globally, has drawn particular scrutiny due to its substantial environmental impact, from resource-intensive production processes to post-consumer waste generation [3]. Consequently, the intersection of technical textiles and sustainability is gaining increasing attention as industries and consumers alike recognize the imperative to minimize the environmental footprint of these materials [4].

Examining the dynamic and evolving relationship between technical textiles and sustainability, with a keen focus on recent advancements, persistent challenges, and promising future trajectories, provides an in-depth exploration of how technical textiles are transitioning from being part of the environmental problem to becoming integral components of innovative, sustainable solutions [5].

Technical textiles are ready to play a critical role in advancing sustainability goals across several sectors, including healthcare, automotive, construction, and environmental protection [6]. Moreover, the lessons learned from the intersection of technical textiles and sustainability can serve as a blueprint for fostering eco-conscious innovation in other industries, ultimately contributing to global environmental objectives [7].

2. SUSTAINABILITY OF TECHNICAL TEXTILES

A focal aspect of sustainability in technical textiles revolves around the materials themselves. Sustainable materials play a central role in reducing the environmental footprint of these textiles. Two notable categories of sustainable materials are recyled fibres and bio-based materials.

Recycled fibers, sourced from PET(polyethylene terephthalate) bottles and post-consumer textile waste, have gathered considerable attention in recent years [1]. Advances in recycling technologies have enabled the production of good-quality recycled fibers, trying to reduce the demand for virgin resources and minimizing waste in the textile industry. One of the driving forces behind the adoption of recycled fibers is the continuous advancement in recycling technologies. Breakthroughs in processes such as mechanical recycling and chemical recycling have made it possible to transform discarded plastics and textile waste into high-quality fibers suitable for technical textile applications [1]. Mechanical recycling involves cleaning, shredding, and melting plastic waste to create new fibers. In contrast, chemical recycling employs innovative chemical processes to break down the polymers into their monomers, which can then be used to produce new fibers [2]. The environmental benefits of utilizing recycled fibers in technical textiles are profound. By diverting PET bottles and textile waste from landfills or incineration, the industry not only reduces the burden on waste management systems but also conserves valuable resources. The production of virgin synthetic fibers typically entails the extraction of fossil fuels and significant energy consumption. In contrast, recycled fibers significantly reduce the demand for new raw materials and the associated carbon emissions [4]. In addition, the use of recycled fibres aligns with the principles of the circular economy, where resources are recycled and reused on a continuous basis, minimising the need for virgin materials [5]. This transition to a circular approach in the textile industry has far-reaching implications, extending beyond environmental conservation to economic sustainability and resource efficiency [3].

Recycled fibers are finding applications in a wide range of technical textile products. In the automotive industry, for instance, these fibers are incorporated into vehicle interiors, contributing to weight reduction and improved fuel efficiency [6]. Their use in protective clothing, particularly in healthcare settings, ensures not only the safety of healthcare workers but also the sustainability of the products through extended use and recycling [4]. Therefore, the increasing recognition of the environmental impact of textiles by consumers has played a crucial role in the popularity of recycled fibers. Consumers are increasingly seeking sustainable products and are willing to chose textiles that align with their environmental values [2]. This consumer-driven demand has prompted manufacturers to adopt recycled fibers in their technical textile offerings, focusing further innovation in this segment.

Despite the significant progress made in utilizing recycled fibers in technical textiles, challenges remain. Cost constraints, particularly in the production and processing of recycled fibers, can hinder their widespread use [1]. Additionally, technological limitations in the recycling process and concerns about fiber quality need to be addressed to ensure the consistent availability of high-quality recycled fibers [2].

On the other hand, bio-based fibers and polymers, derived from renewable resources such as plants and agricultural waste, represent an eco-conscious alternative to traditional petroleum-based materials. These materials offer the potential to reduce the carbon footprint of technical textiles. One of the primary advantages of bio-based materials is their eco-friendly sourcing and processing. Compared to traditional petroleum-based materials, bio-based materials are made from renewable resources, reducing the carbon footprint linked to the extraction of raw materials [5]. These materials are appreciated not only for their environmental benefits, but also for their aesthetic aesthetics and tactile qualities. In healthcare, bio-based materials are used to develop medical textiles such as surgical wound dressings and sterile surgical gowns. These textiles are not only biocompatible but also biodegradable, reducing the environmental impact of medical waste [4],. Moreover, bio-based materials can be engineered to possess antimicrobial properties, enhancing their functionality in healthcare applications.

Furthermore, the cultivation of bio-based feedstocks can promote sustainable agriculture practices, contributing to soil health and biodiversity conservation.

Moreover, smart textiles, integrated with materials like shape memory alloys and conductive polymers, have emerged as a promising avenue for enhancing functionality and energy efficiency [8]. By incorporating sensors and responsive elements, smart textiles can contribute to improved user experiences while minimizing resource consumption.

Unlike traditional synthetic materials that persist in the environment for extended periods, bio-based materials naturally degrade over time, returning to the ecological cycle [5]. This property is particularly valuable in applications where end-of-life disposal is a concern, such as agricultural textiles and geotextiles used in soil erosion control [9]. While bio-based materials offer significant promise, they also present challenges. The cost of production for some bio-based materials can be higher than that of synthetic alternatives, primarily due to limited economies of scale. Furthermore, the mechanical and chemical properties of bio-based materials may vary depending on the source and processing methods, necessitating careful selection and customization for specific technical textile applications [4].

The application areas of technical textiles have expanded, with sustainability considerations at the forefront:

- Protective Clothing: Sustainable developments in protective textiles, particularly in healthcare and firefighting, have gained prominence. These textiles not only enhance worker safety but also contribute to reduced waste through extended product lifecycles [4].
- Automotive and aerospace: These industries are progressively using more and more lightweight and durable materials for vehicle and aircraft interiors. This not only reduces fuel consumption but also aligns with sustainability goals [6].
- Geotextiles: In environmental applications such as erosion control and soil stabilization, technical textiles have demonstrated their sustainability benefits. These textiles support eco-friendly construction practices and environmental conservation [9].

3. ENVIRONMENTAL IMPACT ASSESMENT

Environmental impact assessment (EIA) of technical textiles is a critical element in assessing the sustainability of these materials throughout their life cycle, from raw material extraction to production, use and end-of-life disposal [10]. This holistic measurement empowers stakeholders, including manufacturers, policy makers and consumers, to make well-informed decisions about the environmental footprint of technical textiles.

Life Cycle Assessment (LCA) is the basis for assessing the environmental impact of technical textiles. LCA is a systematic and standardised methodology that quantifies the environmental impact related to a product or process. LCA studies are based on exhaustive data sources, including databases on energy consumption, emissions and environmental impact factors for different processes and materials. Obtaining accurate and up-to-date data, nevertheless, can be challenging, especially for emerging materials such as bio-based or smart textiles. In addition, the availability of data can vary by region, making it important to consider regional differences in environmental factors [10].

Eco-labels and certifications play a crucial role in guiding consumer choices toward more sustainable technical textile products. These labels, such as OEKO-TEX Standard 100 or GOTS (Global Organic Textile Standard), provide assurance that a product meets specific environmental and social criteria [7]. However, standardization challenges and concerns related to greenwashing (misleading environmental claims) must be addressed to ensure the credibility of eco-labels.

One of the key implications of EIA for technical textiles is the concept of design for sustainability. By understanding the environmental hotspots identified in the LCA, manufacturers can make informed design decisions to minimize the environmental impact of their products. This may involve selecting more sustainable materials, optimizing production processes, or designing for recyclability [3].

The environmental impact assessment is not a static process. As technologies evolve and new materials become available, it is essential to revisit and update assessments to account for the latest developments. Continuous improvement in sustainability metrics, data collection methods, and environmental modeling ensures that technical textiles can align with evolving sustainability goals [11].

4. CONCLUSIONS

Recycled fibers represent a crucial dimension of sustainability in technical textiles. Their utilization not only conserves resources and reduces waste but also aligns with consumer demand for eco-conscious products. As technological advancements continue to enhance the viability of recycled fibers, they are ready to play an increasingly significant role in shaping the sustainable future of technical textiles [12].

Biomass-based materials have eco-friendly origin, diverse uses, biodegradability and potential to reduce the environmental impact of textile production make them a strong choice for a more sustainable textile industry. As R&D efforts continue, bio-based materials contribute to both environmental protection and improved product performance [13].

The environmental impact assessment of technical textiles is a multidisciplinary process that assesses the environmental implications of these materials from cradle to grave. Through tools such as life cycle assessment and the implementation of eco-labels, the textile industry and stakeholders can make well-informed policy decisions to reduce the environmental footprint of technical textiles. This process also encourages innovation in materials and processes, eventually contributing to a more sustainable future for the textile industry and the wider global environment [14].

In the contemporary industrial landscape, technical textiles have emerged as a expanding sector with substantial commercial potential. The rapid increase of high-performance textiles, coupled with their versatile applications, has conducted opportunities for innovative utilization [15]. Projections indicate that the market dimensions of technical textiles are ready to exceed an estimated value of US$251.82 billion by the year 2027 [16]. Traditionally, technical textiles were primarily associated with utilitarian products such as wound-care items, diapers, orthopedic braces, prosthetic devices, wipes, respiratory masks, bedding, ropes, and belts. However, technological advancements transformed the range and diversity of their applications. Presently, the domain of high-performance textiles encompasses a wide array of end-uses that extend far beyond their conventional roles [17].

It is pertinent to note that the global trajectory of technical textiles signifies a broader economic trend that transcends the mere production and processing of textiles. A predominant concern that has emerged within this context is the imperative to mitigate the ecological impacts coming from the use of technical textiles, specifically with regards to their effects on soil, air, and water quality [18]. Consequently, there is a expanding need for intensified analysis and investigation in this field.

Looking forward, the landscape of technical textiles portends heightened global competition, with manufacturers actively seeking to diversify applications, optimize production costs, and ensure the delivery of high-quality products. This evolution underscores the dynamic and multifaceted nature of the technical textiles industry as it continues to evolve in response to changing market demands and environmental imperatives.

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FAST FASHION VS SUSTAINABLE FASHION – A PERSPECTIVE FROM CONSUMERS IN SPAIN AND ROMANIA

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Abstract. Consumers across Europe are becoming more conscious of environmental and ethical concerns related to the fashion industry, leading to an increased demand for sustainable and ethically-produced clothing. Despite the growing interest in sustainable fashion, fast fashion brands still remain dominant in terms of market share. Considering the socio-economic and environmental impact of consumers' preferences on the fashion industry, the objective of this research was to study the consumer preference for fast fashion versus sustainable fashion. The data were collected from the Meta database, as well as from Google Trends, based on various demographics, such as: age, gender, and location – the sample consists of fashion consumers from the main cities of Spain, Madrid and Valencia, with the Romanian cities, Bucharest and Iasi. By analyzing the consumers' preference for fashion in different urban centers, one can ascertain the degree to which specific fashion trends influence the clothing choices of their particular residents. This research emphasizes the importance of studying consumers' preferences, the need to shape them towards a more sustainable future, and, also, this paper argues that understanding the trends in apparel manufacturing in different urban areas will enable the development of strategies to reduce the global carbon footprint linked to the fashion sector.

Keywords: *sustainability; fashion industry; consumer' preferences; sustainable development*

1. INTRODUCTION

The global fashion industry has been subject to major paradigm changes in light of the 2030 Agenda for Sustainable Development, which sheds light on dynamics between consumer demand, environmental consciousness, and ethical perspectives [1]. Under the new sustainability paradigm, the fashion industry is undergoing a profound transformation [2,3]. This shift is characterised by increased consumer demand for sustainable clothing, heightened environmental consciousness, and emphasis on ethical aspects [4–6].

Consumers have started to focus on sustainability, being more inclined towards quality over quantity, demanding transparency in the fashion supply chain [7–9]. This has intensified the use of ecofriendly materials [10,11], the reorientation towards circular fashion models [11], and the reduction in the industry's carbon and water footprints [13–15]. Fair labour practices and animal welfare are paramount ethical approaches in this new sustainable paradigm of the fashion industry [16–18]. Brands that show respect for these values and sustainable practices are gaining consumers' favour, while those that stay indifferent to the imminent transformation face the risk of losing market share [19]. Thus, the fashion industry is witnessing a significant increase in accountability, transparency, and environmentally friendly practices.

Across Europe, consumers become more and more aware of their impact of clothing choices and attitudes on the natural capital and on society, in general [20]. This sustainability-momentum in the fashion industry has capitalized on an increase in the demand for environmentally-friendly and ethically-produced clothing [21]. Moreover, the consumers' preference for sustainable fashion has maintained and remained resilient in the face of crisis, such as the one caused by the COVID-19 pandemic [22–25].

For example, Sweden is well-known for its thrifting culture – popular thrift shops like "Myrorna" and "Stadsmissionen" mark the ground for Swedish consumers in the direction of circular economy through second-hand clothing behaviours [26]. Swedes take pride in finding stylish and affordable second-hand clothing, which is a sustainable fashion trend that minimises waste and leads to the achievement of the Sustainable Development Goals (SDGs) [27]. French consumers have embarked on a journey towards sustainable fashion with brands like Veja [28], which produce sneakers by resorting to environmentally friendly materials, ethical labour policies, transparency, and commitment to sustainability. The Netherlands is one of the countries at the forefront of circular fashion initiatives in the European Union, which has become a complementary industry to the agricultural industry, in a highly sustainable manner [29]. A good example to highlight this strong symbiosis between the two industries is Fruitleather Rotterdam, a sustainable circular business created by Koen Meerkerk and Hugo de Boon, two young designers who found a manner to capitalize on the fruits that lack aesthetic standards and, consequently, are rejected by supermarkets. The business is focused on transforming the rejected fruits into leather-like material, which is later used in fashion, providing an innovative and sustainable alternative to the polluting practices of the leather industry [30]. In Denmark, brands resonate with consumers who try to become more sustainable by seeking fashion with a conscience – for example, "Ganni" is a Danish brand with approximately 50% of the fabric composition certified recycled, lower-impact, or organic. As part of their carbon insetting scheme, Ganni has installed solar panels with their Portuguese supplier, in the race to achieve 50% greenhouse gas emission reduction by 2027 [31]. In the United Kingdom, a surge in rental and resale platforms like "HURR Collective" and "Depop" has been noticed [32]. Such platforms dedicated to fashion deliver sustainability by enabling consumers to rent/sell pre-owned clothing, extending the product lifecycle and reducing waste.

As far as Spain and Romania are concerned, both are witnessing a healthy shift towards sustainable fashion practices, especially if considering the emergence of local eco-friendly brands, increased awareness of ethical issues, support for local artisans, as well as the adoption of circular fashion models [33–35]. These trends stand proof of a larger global movement towards a responsible and environmentally-friendly fashion consumption model, in the spirit of the 2030 Agenda for Sustainable Development [36].

With a strong commitment to eco-friendly materials, "Ecoalf" is one of the many prominent sustainable Spanish fashion brands, specialised in designing and producing stylish clothing, as well as accessories made from recycled materials, including ocean plastics [37]. Madrid and Barcelona host Sustainable Fashion Week, an event that encourages brands and designers to promote eco-conscious fashion [38], thus raising awareness about responsible fashion choices – not only among Spanish participants, but at a large scale, considering the attractiveness of such important fashion events among fashion consumers. Moreover, Spain is considered home to some responsible textile manufacturers and fashion brands that take pride in delivering sustainable production – "Textil Santanderina" is one of the best examples in this regard [39], as it adds more value to achieving the SDGs by focusing on water and energy conservation.

In Romania, big cities like Bucharest host thriving vintage shops, second-hand boutiques, and fashion markets [40]. Customers are increasingly attracted to these types of fashion outlets, not necessarily because of economic considerations [41], but because they recognize the environmental benefits of extending the life of clothing items and of fostering sustainability through reducing the demand for new production [42]. Romania has a rich tradition of fine artisanal craftsmanship, which includes weaving, embroidery, and the manufacturing of traditional fabrics [43]. Many ethnic designers and artisans harmoniously blend these traditional techniques into modern clothing, ensuring both environmental sustainability and cultural preservation. In addition, universities in Romania are progressively providing courses and programs in applied sustainability practices, including in the case of the fashion industry. For example, at the Faculty of Agri-food and Environmental Economics (part of the Bucharest University of Economic Studies), disciplines such as ecomarketing, strategies for sustainable consumption, circular management of resources, and ecoentrepreneurship are part of the syllabus, which prepares future professionals to manage constantly challenging and changing industries, the fashion industry being no exception. Thus, by providing interested individuals with the necessary information and abilities to efficiently adopt sustainable practices, it becomes more facile to deliver positive societal changes and foster a fashion industry that is characterized by responsible and ethical behaviours. Yet, this change is slowed down by the phenomena of fast fashion.

The fast fashion phenomena is noticeable in almost all the major cities of the European Union and is distinguished by the accelerated and ever-evolving approach of apparel manufacturing, distribution, and consumption within the fashion industry [44]. Fast fashion brands highly value speed in the clothing production process, often resulting in just a matter of weeks for products to transition from the design phase to their final placement on store shelves, as opposed to sustainable fashion cycles, which tend to follow a more lengthy timeline, spanning several months [45–47]. Fast fashion brands actively and closely monitor the latest fashion trends showcased on runways and within popular culture, while their main objective is to expeditiously copy these trends and then make them accessible to a broad customer base at affordable price points [48], many times disconsidering the environmental price [49]. The fast fashion industry heavily relies on the utilization of global supply chains for the procurement of materials and establishment of production facilities [50]. This strategic approach aims to achieve cost efficiency in order to satisfy customer demands for affordable prices [51]. Nevertheless, as a consequence of the affordable price and apparent transience of fast fashion products, consumers frequently engage in excessive clothing consumption, acquiring more clothing than necessary and subsequently discarding them after minimal usage [52]. This trend has given rise to significant apprehensions regarding the sustainability of such practices, which oftentimes result in adverse environmental consequences. The fast fashion model has been extensively linked in the literature to several environmental issues, including but not limited to excessive waste generation, increased resource consumption, ethical dilemmas concerning labour practices [53–55]. Furthermore, it should be noted that the fast fashion model perpetuates a culture of perpetual consumerism, wherein consumers are incentivized to consistently acquire new products in order to maintain their trendy status [56]. Thus, while it does ensure accessibility and affordability to customers, the phenomenon of fast fashion has also been raising concerns about aspects related to sustainability, ethics, and to the long-term consequences for the natural capital.

The objective of the research conducted in this conference paper was to study the consumer preference for fast fashion versus sustainable fashion from the main cities of Spain, Madrid and Valencia, with the Romanian cities, Bucharest and Iași, based on various socio-demographics, such as: age, gender, location, and also based on their digital "footprint", referring to their engagement with fashion brands on Meta-owned social platforms. Robustness is added to the research by studying the consumers' interest in brands based on Google Trend Scores. The study of consumers’ preference for fashion is valuable when assessing the degree to which specific fashion trends influence clothing choices and contributes to the construction of a sustainability roadmap for the fashion industry. Thus, studying consumers’ preferences is essential in order to be able to provide more sustainable fashion alternatives based on real consumer needs, which would lead the way to a more sustainable future with a cleaner fashion industry and responsible consumers.

The novelty factor of this research resides in the framework of analysis. The socio-demographic profiles and digital "footprint" of fashion enthusiasts from Spain and Romania were collected and assessed by resorting to Meta Audience Insight and Google Trends data. Empirical research findings were discussed in light of the self-designed framework of analysis dedicated to the study of consumer preference for fast fashion versus sustainable fashion. Proposals for the transition to the sustainable fashion model were made while taking into account the particularities of each fashion consumer typology, as defined in the unique research methodology explained in the experimental part of the conference paper.

2. EXPERIMENTAL PART

This empirical study employed a wide range of datasets in order to ensure high-quality research findings. To investigate the consumer preference for fast fashion vs. sustainable fashion from the main cities of Spain and Romania, data relevant to this topic were gathered in September-October 2023. The statistics utilised for this study were obtained from Meta, previously recognised as Facebook [57]. The Meta-owned datasets are valuable sources of information regarding fashion consumers, considered suitable for this research. Resorting to this source has demonstrated its worth in academic research, with results often being validated when the research methodology is appropriately implemented. With regard to this particular study, two Audience Insight queries were executed with the following parameters: "Interests: H&M, Primark, Stradivarius, Zara, Pull&Bear, or Mango" – as a proxy for fast fashion preferences, and "Interests: sustainable fashion" as a proxy for sustainable fashion. Statistics were gathered based on gender, age, and location. Data regarding the Google Interest Score were collected during the same period by systematically querying the Google Trends database [58], according to the terms: "Primark", "Stradivarius", "Zara", "H&M", "Pull&Bear", and "Mango" – all of them being recognized as fast fashion brands [59].

Raw data collected were processed and statistical analyses were carried out regarding the consumers' preferences concerning fast fashion versus sustainable fashion, while taking into account the importance of filtering the results based on criteria such as location, gender and age group. The sample was described in Table 1. Carbon footprint estimation would have been a great addition to the filtering of the results [60], but due to data availability that was not possible at the moment of carrying out this empirical research. The results and discussion section begins with the analysis dedicated to the consumers' preferences for fast fashion, then it is followed by the analysis regarding sustainable fashion. Lastly, robustness is ensured through the Google Trends analysis.

3. RESULTS AND DISCUSSION

Research findings show that there is a greater level of interest in fashion among women compared to males, regardless of whether it is fast fashion (Figure 1) or sustainable fashion (Figure 2), a pattern which was noticed for all analysed cities – both Spanish and Romanian. For both countries, the interest in fast fashion is declining more rapidly for men than women if age increases and the interest in sustainable fashion is increasing in the case of women once age increases, whereas the situation is the opposite for males.

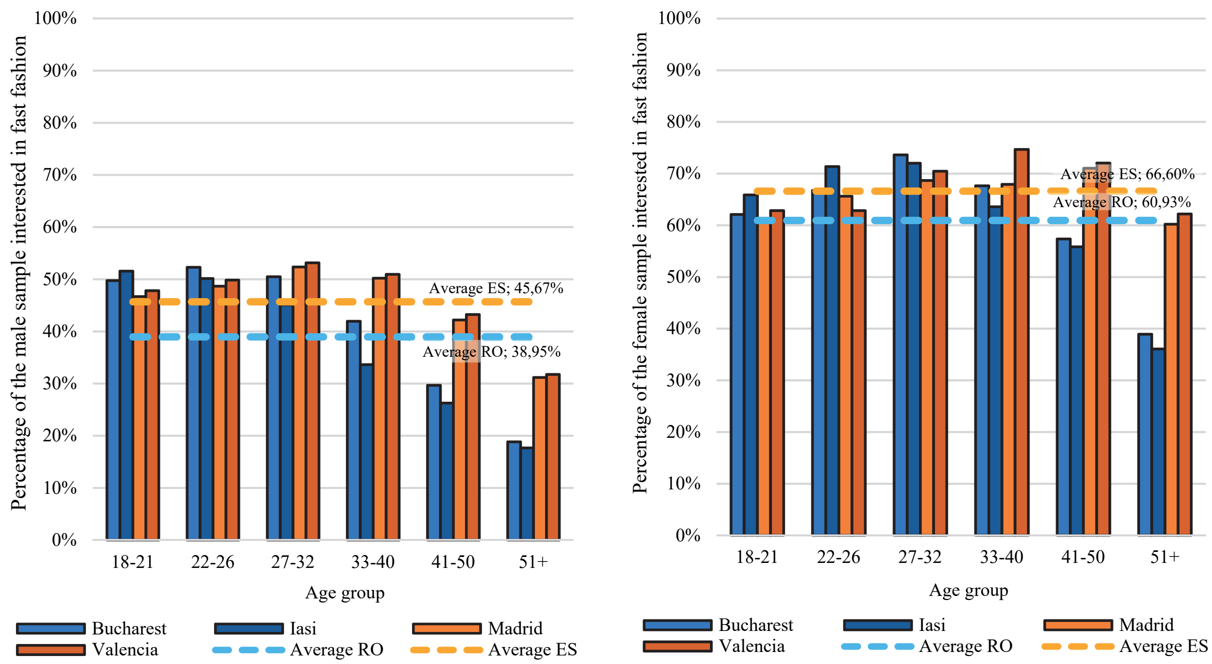

Figure 1. Fast fashion preferences analysis based on location, gender and age group

Source: Author's graphical representation of the processed Meta data (2023)

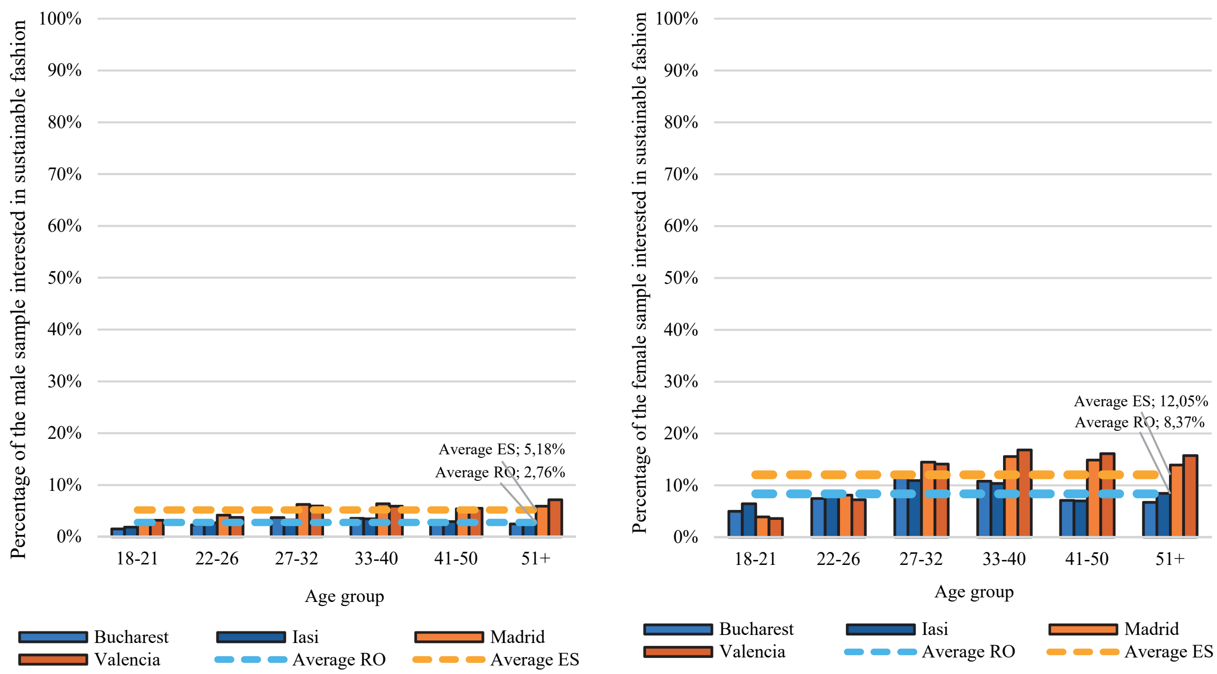

Figure 2. Sustainable fashion preferences analysis based on location, gender and age group

Source: Author's graphical representation of the processed Meta data (2023)

Table 1.
The number of population with a linked Meta account

City		Bucharest	Iasi	Madrid	Valencia	Bucharest	Iasi	Madrid	Valencia
Gender		Female				Male			
Age group	18-21	81,800	21,700	206,600	69,200	59,500	16,100	167,700	50,200
	22-26	160,600	38,400	352,100	106,600	139,600	33,300	323,600	87,900
	27-32	142,200	29,300	393,000	100,600	145,400	27,700	359,200	90,700
	33-40	208,000	35,700	464,100	110,600	193,800	34,500	390,100	101,500
	41-50	197,200	34,200	531,300	153,200	194,100	33,900	468,700	134,100
	51+	268,600	53,200	651,000	206,900	217,600	39,600	549,000	166,800

Source: Meta data (2023)

Only 2.76% (Romania) and 5.18% (Spain) of males are interested in sustainable fashion, whereas women can be even three times more prone than men to adopt this type of fashion. An inflection point between Spain and Romania is that age increase triggers a rise in the level of interest in sustainable fashion in the case of Spaniard women, whereas the opposite was observed for Romanian women. The older Romanian population is not familiar with the concept of sustainability, which is one of the negative consequences of the communist regime. To provide robustness to research findings, the evolution of the Google Interest Score for fast fashion brands was analysed in Figure 3 (Spain) and Figure 4 (Romania).

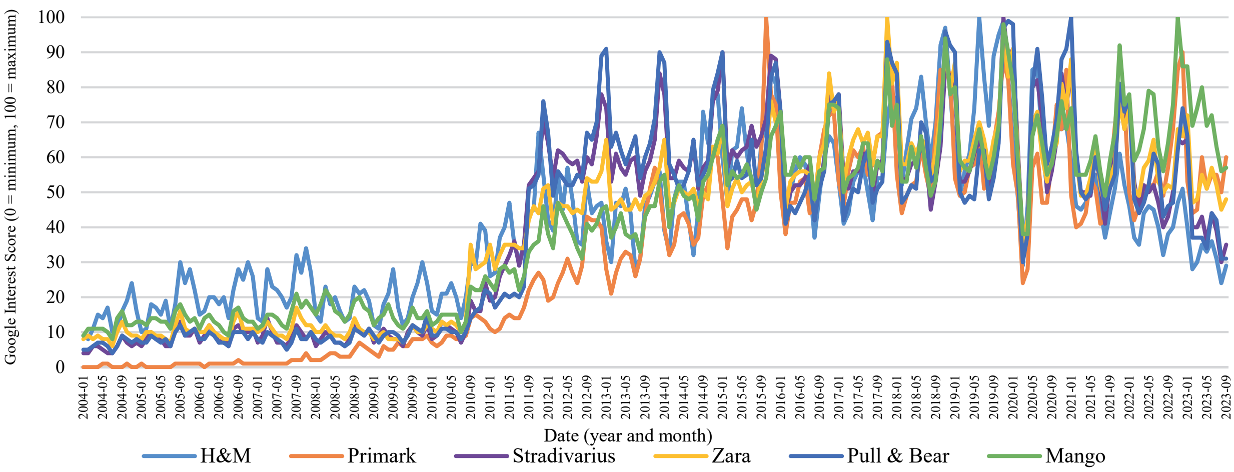

Figure 3. Google Interest Score evolution for fast fashion brands in the case of Spain

Source: Author's graphical representation of the data extracted from Google Trends (2023)

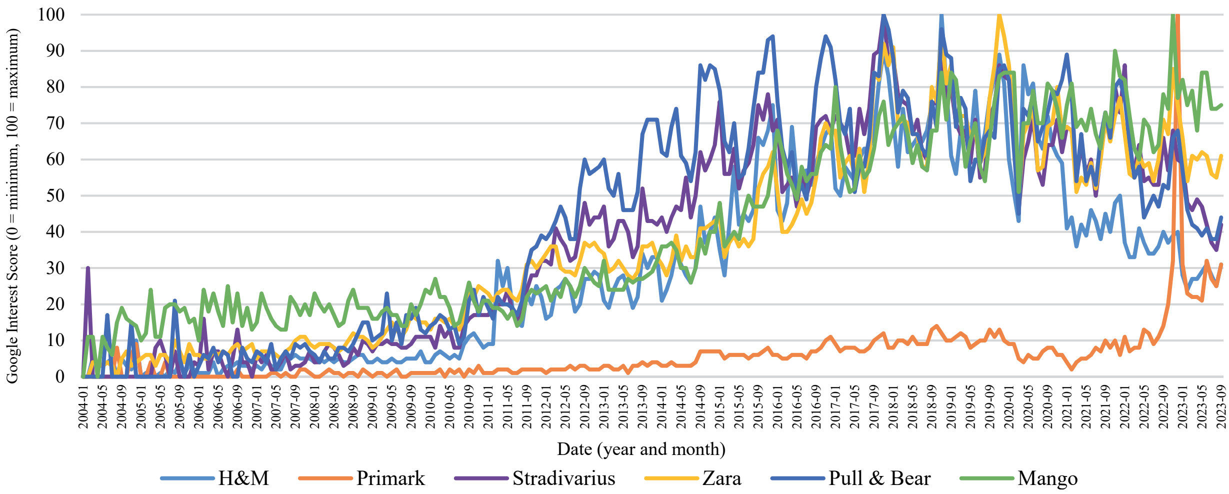

Figure 4. Google Interest Score evolution for fast fashion brands in the case of Romania

Source: Author's graphical representation of the data extracted from Google Trends (2023)

The analysis of the evolution of the Google Interest Score shows a longer history for Spain in the favour of fast fashion brands, with a significant rise in the year 2010. This result validates the initial conclusion reached based on Meta data, regarding Spaniards being more fond of fashion than Romanians. In Romania, the interest in fast fashion has intensified one year later than in Spain. In addition, the interest in a big brand, Primark, has only grown in Romania after the first shop was opened recently, in 2022.

4. CONCLUSIONS

The beginning of the twenty-first century marks a period of major societal importance regarding the ongoing clash between fast fashion and sustainable fashion. This clash has developed in reaction to important factors: primarily, the observable environmental repercussions of the fashion industry, encompassing its major part in pollution, depletion of resources, and development of waste. Furthermore, there has been an increased focus on ethical considerations regarding labour conditions within the business, highlighting the imperative for fair and secure operations. Simultaneously, the evolving consumer preferences which place a higher emphasis on sustainability and ethical values have significantly influenced the dynamics of the market and prompted transformations in industrial processes.

In addition, a growing trend towards more stringent regulations was remarked in the case of the fashion industry, as countries and international organisations are enacting mandates to promote sustainability and ethical practises. Fashion brands are required to comply with and adapt to these regulations. Moreover, the sector is being facilitated in its incorporation of eco-friendly practises by technological developments in sustainable materials and manufacturing methods. The rise of the circular fashion sector, characterised by its focus on recycling, reusing, and waste reduction, has garnered momentum as a feasible alternative to the conventional linear fashion paradigm. Thus, the fast fashion vs. sustainable fashion debate is an ardent topic with a profound impact on the cultural, environmental, and socio-economic aspects of the fashion industry.

Since the level of interest in fashion and the extent to which sustainable fashion practises are embraced by customers can differ among countries as a result of many cultural and socio-economic factors, the main contribution of this research resides in the empirical insight provided regarding the consumer preference for fast fashion vs. sustainable fashion from the main cities of Spain (Madrid and Valencia) with the Romanian cities (Bucharest and Iasi), based on socio-demographics, as well as digital "footprint" specific to their engagement with fashion brands on Meta-owned social platforms. The Spanish population generally demonstrates a greater inclination towards fashion in contrast to their Romanian counterparts, and this variation can be linked to various significant factors. One of the key factors that contribute significantly to this disparity can be attributed to the historical setting of Romania, which is still enduring consequences of communism, visible in many socio-economic contexts, including the context of the fashion culture.

The enduring impact of communism in Romania is characterized by prolonged economic difficulties and restricted access to global fashion influences. During this particular period, the primary emphasis was directed towards utilitarian and standardised attire, rather than fashion as a means of personal expression or individualistic endeavour. Consequently, the growth of the fashion culture in Romania have exhibited a slower pace in comparison to nations with more extensive backgrounds in market-oriented fashion, like Spain, whose economy is comparatively more advanced and varied, affords its populace with higher disposable money, hence facilitating greater engagement in fashion-related pursuits and expenditures. The culture of fashion consciousness is further enhanced by the urbanisation and cosmopolitan nature of Spanish towns. In relation to the adoption of sustainable fashion, as research findings show, Spaniards exhibit a greater inclination towards embracing eco-conscious practises in comparison to Romanians. There are other elements that contribute to this disparity. Spain exhibits a larger gross domestic product per capita, ensuring enhanced financial capabilities for Spanish consumers to actively engage in the area of sustainable fashion. Additionally, Spain boasts a well-developed fashion industry, characterised by the presence of sustainable fashion businesses and designers. The increased availability of sustainable fashion solutions has the potential to enhance accessibility and attractiveness among the Spanish population. Furthermore, Spain may exhibit a more robust fashion culture that prioritises ecological awareness, which can be attributed to heightened levels of knowledge, education, and media attention to sustainability concerns.

The very weak interest in sustainable fashion in the case of Romanians noticed in this empirical research can be partially explained by the lasting effects of communism. The presence of ongoing economic issues serves to constrain the amount of spare income that individuals have at their disposal for fashion-related expenditures. Furthermore, the process of transitioning to a market economy has been characterised by intermittent periods of instability, so posing further obstacles to the establishment of a thriving fashion industry and a vibrant consumer fashion culture. Although Romania may exhibit some level of interest in fashion, it is noteworthy that this desire may be relatively subdued and less inclined towards sustainability.

This empirical research, although it does provide valuable insight regarding the consumers' preferences in fashion between Spain and Romania, it is still subject to various limitations. Firstly, this study was focused on four specific cities – two in Spain and two in Romania, which overlook the regional and national overall context. Secondly, data were collected from the Meta database and only citizens with accounts linked to Meta platforms were analysed in this study. Thus, this quantitative study can be further refined by resorting to more comprehensive databases or even complementary ones. Future research endeavours may consist of implementing more comprehensive qualitative investigations, which might involve the utilisation of interviews and questionnaires to effectively capture the diverse fashion preferences of the Spanish and Romanian consumers. In addition, this research can also be replicated at the level of other countries than the ones studied in this conference paper. Lastly, conducting an investigation into the impact of marketing and media on the adoption of sustainable fashion, as well as analysing the significance of education and cultural elements in determining consumer fashion preferences, will contribute to a more comprehensive understanding of these phenomena within the contexts of Spain and Romania.

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EXPLORING SUSTAINABLE FIBRES FROM CREATION TO APPLICATION IN THE ULSTER UNIVERSITY BELFAST CAMPUS TEXTILE ROOF GARDEN

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Abstract. *This paper investigates a recent project that focussed on creating natural fibre composites for a range of applications and products. The project included the use of locally sourced materials including hemp, wool, flax, and wood pulp. Using action research as a methodology it tracks the design, development and creative use of materials and the various fibre combinations for the desired functionality of the products. One of the outcomes was the design and development of the natural fibre composites for use in the build of a textile roof garden based on the 6th floor of the newly built Ulster University Belfast Campus, in the heart of the city centre. The project was funded by the Department of Agriculture, Environment and Rural Affairs (DAERA) through the School Pollinator grant and the Physical resources department at Ulster University. The textile roof garden used the mixed materials in the overall design of the external planters and structures in the garden, to showcase the potential for the new materials and future applications. The textile garden was also designed to be used as an educational tool highlighting the intensity and complexity of the systems required in the growing, processing and refining of the bast fibres. The purpose was to also educate students, staff, and the public through the garden design and as an aid to reconnecting with textile materials. It was also to be a tool to review and reflect on the importance of textiles for individual choice and behaviour regarding textiles. To assess the biodegradability of the materials they were combined with the soil to view the rate of the material decomposition. The fibres were also measured for the nutritive qualities for the soil and to consider the possibilities for climate beneficial fibre production.*

Keywords: *textiles, fibre, composites, wool, flax, hemp.*

1. INTRODUCTION

The Textile Roof Garden Project was designed for installation on the 6th floor on the Belfast Campus, it is adjacent to a Vegan Café. As part of the new Campus development, the focus of the research was to design a garden that would promote biodiversity and enhance a grey space on the City Centre Campus while reconnecting staff, students and the public to a greater knowledge and understanding around the growing processes aligned to textile fibres. The negative impact of textile waste on our environment has been well publicised with over 8000 tons going to landfill in Northern Ireland alone. According to Fashion Revolution "we can have any fabric, material, ink, or dye shipped directly to our door at the click of a button and we are disconnected from the practices, skills and methods required to grow and produce these materials." [1] The rationale behind the design of the textile garden was inspired by Lottie Delamain's textile garden created for the Chelsea Flower Show in 2022, and to realise the potential resources we have available locally exploring how to use them in creative ways. Many plants used in textiles are native to Northern Ireland, and offer biodiversity, are undemanding in terms of water and are easily propagated and grown. The project desired a similar outcome to that of Delamin's "to re-establish the connection between plants and textiles, reveal the beauty to be found in plant-based dyes and fibres, and sow a seed of curiosity about what we wear." [2] The roof garden was designed to enhance the environmental quality of the campus by planting a variety of plants for pollinators. With careful curation and selection to optimise the best 'textile and bast' plants for pollinators with good structures for fibre and as a source for drawing resources. There was also an expectation to both improve access to, and quality of, outdoor spaces for students, staff, and the public by being closer to nature. The project was designed to increase the biodiversity value of the area by planting for pollinators, the area identified was concrete and therefore the project proposed to transform an unused space into a valued environment by creatively greening a grey space. New research from wellbeing charity Inspire and Ulster University [3] found students/people working in the creative industries in NI are almost three times more likely to suffer from mental ill health than the general population the project will be accessible to all students and staff on the Belfast Campus with calming spaces to work in, that will also provide inspiration and education. Opportunities for outdoor learning workshops, drawing projects and resources were to be established as part of the project outcome. The textile roof garden project is also aligned to Ulster University's strategy 'People, Place and Partnership' which states that, "Our purpose is to build sustainable futures for all in society…our research is addressing the grand challenges of the world… We will support our people to continue making a profound and sustainable contribution to social, cultural, and economic development across the society we serve." [4]

The disposable world we now find ourselves in cites textiles as one of the key polluters next to oil. Education needs to reconnect with how textile fibre is grown, harvested, and processed. Designers and makers should understand the chain from farm to fabric to fashion/textiles. Only then will we be able to produce the best products for the future. The origin of clothes can be found in the forest and the farm. Providing habitat for bio-diverse plants and insects for textile production has been evidenced by research undertaken by Fashion Revolution, [5] Redress [6], Ellen McArthur Foundation [7], and the European Textile regulations biodiversity strategy. [8]. Using and earth-centred design approach and moving away from fast fashion and harmful textiles to a slow circular and more mindful way of operating.

Building on an IntertradeIreland funded project with Donegal yarns where a range of natural locally sourced and processed Irish wool was developed for the textile market. During the project the wool fibres were blended with polymer fibres and/or hemp fibres it was decided that they should be incorporated into the garden in the form of composites. With the theme of creating a sustainable textile garden this would provide a showcase highlighting the need to use natural fibres and move away from carbon and fossil fuel-based fibre in products. The project also related to earlier research developed at the *Does Design Care…?2* Workshop held in Chiba Japan, resulting in 'T is Time for Trust.... to actively collaborate to address the challenges of the Anthropocene" [9] outlining that design has a key role to deliver change with the 'Does Design Care...?! Head-to-Head debates stating that 'there is a real sense of urgency this is the key issue to return from the precipice of disaster. We need to bring the masses with us, and design can do this." [10]

A circular design model for textiles and fashion, described by the Ellen Macarthur Foundation establishes that "…business models, products and materials are designed to increase use and reuse, creating an economy in which nothing becomes waste, and everything has value." And it represents "an opportunity to fundamentally redesign our economic model to benefit society businesses and the environment." [11]
Fibreshed discusses a soil-to-soil approach where a "place-based textile system a *fibreshed…*focused on the source of the raw material, the *transparency* with which it is converted into clothing, and the *connectivity* among all parts, from soil to skin and back to soil." [12] The use of natural plant dyes and fibres such as flax, hemp, wool, indigo and woad are being grown and "ameliorating the causes of climate change, increasing resilience to drought and rebuilding local economies." [13]

2. HEMP AND WOOL FIBRES

The main fibres used for experimentation in the project composites were hemp, flax, and wool. Historically Northern Ireland was world reknowned for their textile industry, with Belfast described as the *Linenopolis*. [14] Also renowned for hemp, from 1897 Belfast exported goods across the globe and in 1904 employed over 3,000 people at the Belfast Ropeworks with 100,000 customers globally. The fast-growing plant has been grown for thousands of years for its fibres, which were traditionally used for rope, textiles, and paper. Wool has also been a valued commodity for Northern Ireland. The first settlers in Ireland kept sheep for their wool, milk, and meat, wool has always been important to the economic, political, and social history of Ireland. Today wool is seen as a category 3 waste product, with sheep being primarily bred for their meat.[15] The Galway Wool Coop have developed a "farmer-owned and run co-operative supplying Galway Wool which is an Irish grown bio-fibre. Galway Wool is rare heritage wool grown with care and pride from our native Irish Breed of Sheep" [16] Sheep are part of the natural carbon cycle, consuming the organic carbon stored in plants and converting it to wool. Fifty per cent of the weight of wool is pure organic carbon.[17]

According to Northern Ireland Hemp Association, hemp offers over 10,000 diverse industrial applications including; bioplastics, construction, food and beverages, textiles, paper, composite panels for the automotive industry, food supplements, other composite materials and biofuels. [18] Industrial hemp is the perfect carbon sink because it absorbs more CO2 per hectare annually than any other commercial crop or commercial forestry. Hemp grows to between 1.8 and 4.5 metres tall in four to five months in Ireland.[19]

During the IntertradeIreland Donegal Yarn project a range of fibres were developed and tested a 100 kg blend of 60% Irish wool and 40 % hammermilled hemp was blended at Donegal yarns Ltd and sent to a UK company experienced in making wool underlays. Felts of 800, 1000, 1700 and 1800 grams per square metre were produced.

Figure 1. Raw Hammermilled Hemp - droppings from the dehairing machine -dehaired and carded

Figure 2. 60% Irish Wool and 40% Hemp Spun into 1/3.6NM:280 Tex Yarn – knitted on a 5gg machine and then woven on a weavebird loom: Images by author

Figure 1 shows hemp fibre from the raw hammermilled hemp state through the dehairing and carding stage. The fibres were then processed into a 60% Irish wool 40% Hemp Spun yarn with a yarn count of 1/3.6NM:280 Tex, with a twist 7.5 Turns per inch and a strength of 28 CentiNewtons.

Figure 2 This fibre was spun into 1/6s and then tested both through the knitting and weaving processes, the knitting was completed on a 5 gauge washed at 60º C, and then stretch dried and then tumble dried for 10 mins.

Figure 3 below shows the loom state of the woven 60/40 Irish wool/hemp yarn from first trial fabric hand woven on a 16-shaft weave bird loom. The hemp wool fibre was hand woven into a plain weave and the hand-woven fabric was then finished by washing out the lanolin stretched to dry and then a further 10 minutes in the tumble dryer to raise the nap.

Figure 3. 60/40 Irish wool/hemp yarn from first trial fabric hand woven on a Weavebird loom – 16 shaft loom in plain weave – hand woven fabric was then finished by washing out the lanolin and 10 mins in the dryer. Image by author

Figure 4. Preparation of 60/40 Irish Wool Hemp for Non-woven fabric for testing with the bio-resins. Image: Chris Weiniger

Yarn produced was to be both knitted and woven to assess its physical properties and appearance. The hemp wool blend was then developed by a local company based in Northern Ireland. Testing around the correct use of bioresin to enable a stable panel for the roof garden. The outcome of this would determine both the form and function of the panels or products.

The 60/40 Irish wool/hemp fabrics were produced and sent to for testing for the bio resin infusion in Northern Ireland. The following meterage and weights were tested with the bio resins to see which would be the most successful in terms of absorption.

- 5M length 800 grams per square metre
- 5M length 1000 grams per square metre
- 5M length 1700 grams per square metre
- 11M length 1800 grams per square metre

The final weight was selected 1800 grams per square metre to maximise the amount of fibre to resin ratio.

3. HEMP AND WOOL COMPOSITE PANELS

All 4 weights ran very well producing excellent strong felts with good aesthetic qualities. Early observations from the trials provided enough information to show that future production on a commercial basis looked feasible. The composite company worked with a range of Bio-based Resins and the most successful one for the absorption into the natural fibre was Resoltech 1800 ECO using a Biobased Infusion System with an approx. fibre percentage by weight being 44%.

All fibres were locally sourced, there were some load bearing issues regarding the roof and as a result we selected specially prepared lightweight soil specifically for roof garden design and combined the lightweight soil with hempchar or bio char – which is charcoal produced by a pyrolysis of biomass often used to improve soil in both sequestration and soil health benefits. Locally sourced Irish trees and plants were procured to decorate the garden and attract the pollinators and by using waste cardboard and fibres from the project in a no-waste approach to create an environmental habitat for insects.

3.1. Composite panel

Following the developmental work of the co-mingled fibres hemp and wool they were made into a hard surface composite using a biobased infusion system **Figure 5**. Testing was undertaken by a local company, with a focus on locally sourced materials and locally developed products in line with a closed loop circular economy approach. It was decided that further testing would be required on the roof with exposure to UV rays and diverse weather conditions as a first stage testing period prior to further work. The results of this exposure will be tracked over the next year to review the impact of a range of weather conditions.

Figure 5. Irish Wool and Hemp comingled on the right hand side with the bio resin added on the sample to the left (darker brown) Image: Chris Weiniger

3.2. Felted fibre

Felted fibre was developed from the Galway Wool as a base fabric and the birrs created at Donegal Yarns Ltd – the waste fluff from the yarn production was then added to the base fabric via a needle felting process on the FELTLOOM ©. See **Figure 6.** The 'birrs' or flecks of coloured fibres come in a diverse range of colours and are used to create the tweed effects through the spinning process in the Donegal yarns but can also be used for an interesting and decorative way for the panneling in the garden. This could also be used to embed the Irish seeds during the growing season to attract the pollinators into the garden. The base fabric was made from 100% pure Galway wool, the only native breed sheep to Ireland, with a unique texture and quality to the fibre.

Figure 6: Placing the birrs and the waste wool on the base of the Galway Wool Felt for needle felting, Image by Author

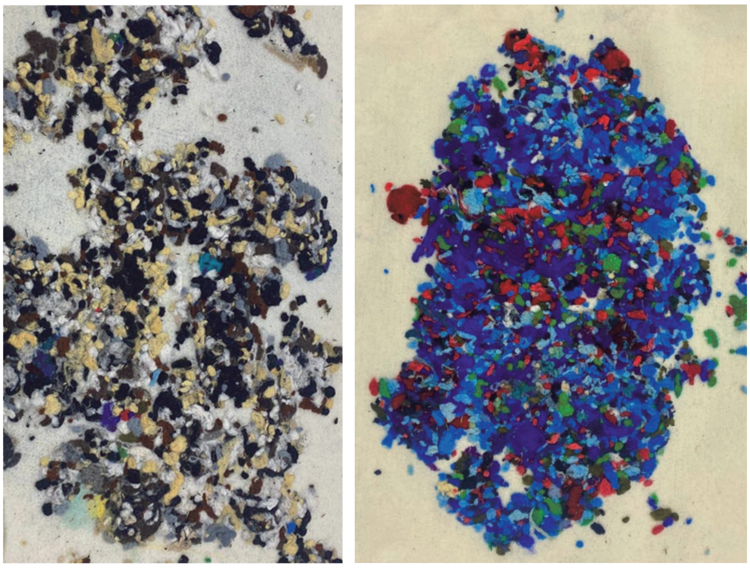

Figure 7. Galway Wool and Donegal Birrs needle felted in 2 different colour ways: Image by Author

The Textile Garden Project desired to use locally sourced materials in the garden build along side growing them. The Irish wool blended with the hemp created an aesthetically pleasing panel and both Donegal Yarns and CCP Gransdens were interested in using the outcome of the composite panels to promote and showcase the use of natural fibre composites not only for use in a garden but also products for the interior and auto industries. Using design-led solutions to industry challenges to achieve the desired goals for net zero carbon and address the climate crisis are using Earth as their client as Nesser describes

”Material start ups should have Earth as their client to make environmental challenges part of the innovation process. He believes that designers have a superpower, which he refers to as ‘Earth positive design’" [20]

This has also been reflected this year by Worth Global Style Network -the global authority on trend forecasting and analytics stated in their recent overview of their Society, Technology, Environment, Politics Industry and Creativity (STEPIC) drivers that ‘Earth is now our only shareholder” and “if we have any hope of a thriving planet…it is going to take all of us doing what we can with the resources we have.”[21]

4. CONCLUSION AND FUTURE RECOMMENDATION

The materials generated for the project have shown a successful production of both a functional and aesthetic product to enhance the environmental quality of the campus by planting a variety of plants for pollinators. The Textile Garden Project will have significance and reach on many levels. It will impact the climate crisis through the use of natural fibre composites and the valorisation of waste materials. It will have a positive impact for both those involved in the build and for the end user experience. The research outcomes will be tracked with the materials for the build will be monitored over the next year, in the roof garden area. Fibre will also be embedded in the lightweight soil, including lyocell, wool, hemp and melt-blown plastics. The composite materials, and wools exposed to the elements will be monitored for their durability and the wool will be monitored for its ability as a substrate for the irish seeds. The planting has been carefully curated and selected to optimise the best 'textile and bast' plants for pollinators with good structures for fibre and for using as a source for drawing resources. There is a desire to improve access to, and quality of, outdoor spaces for students, staff and accessing public and transform an unused space into a climate beneficial environment through creatively greening a grey space. It is also proposed that the Textile Garden Project will improve the health and wellbeing of those on campus with new research from wellbeing charity Inspire and Ulster University finding that people working in the creative industries in NI are almost three times more likely to suffer from mental ill health than the general population. The project will be accessible to the general public, however students and staff on the Belfast Campus will directly benefit from a green space that will be calming while additionally providing inspiration for drawing and making with a focus for best practice around the use of materials, highlighting the impact of the climate challenge in textiles and fashion. We plan to involve our own student groups and outreach collaborators, using slow approaches to developing skills including spinning, weaving, knitting, sewing. External collaborators will be invited to create the raised beds and work on the planting. The University Estates/Gardeners along with student volunteers will maintain the garden in the 3 years following planting. We plan to establish a Textile and Fashion Garden Society to secure future funding for maintaining and developing the space. Our industrial partners are already integrated into the space with reuse of materials for the composites including the use of waste wool alongside the natural fibre composite, which will showcase the possibilities for scalable eco approaches for textile products to replace the use of plastics. The Textile Roof Garden Project research has also been cited in an AHRC Design Exchange Partnership Project Restoration & Redesign: A circular system economy for a coastal community' [AH/Y000226/1] (48K) and the successful bid for the AHRC Green Transition Ecosystem and the Future Island-Island [AHY003780] (4.6M). The project ideas and materials are to be developed in grey sites across Belfast, in collaboration with Brink [22] with the support of the City Councils Belfast 2024 project. The Textile Roof Garden while a tool to reconnect and educate through a circular design model, the regenerative principles will create opportunities for economic growth and address climate action. It will also engage and care for the community's health and well-being by providing a place to relax enjoy that has an aesthetic beauty and for fauna and flora to thrive in a city scape.

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FORECASTING THE MECHANICAL BEHAVIOUR OF SUCROSE-CELLULOSIC STRUCTURES FOR TAILORING FLEXIBILITY THROUGH MOLECULAR DYNAMICS SIMULATIONS

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Abstract. *Automating fabric handling within sewing manufacturing presents a multitude of benefits in terms of efficiency and precision. Nevertheless, it introduces considerable initial complexity and potential rigidity. The intertwining trends of fabric adaptability and the integration of robotics into sewing manufacturing can yield more efficient, versatile, and cost-effective textile production. By combining the ability to work with diverse fabrics and designs with the precision and automation of robotic systems, textile manufacturers can enhance their competitiveness in the global market while satisfying the increasing demand for customization and quality. Fabric strength, a crucial attribute influenced by factors such as fibre type and finishes, necessitates careful consideration. Molecular dynamics (MD) simulations have emerged as a valuable tool for gaining comprehensive insights and an in-depth understanding of the mechanical properties of materials. Utilizing MD simulations to predict fabric bending stiffness properties holds promise for cost-effective textile research and development, especially when experimental data on mechanical properties are scarce. This study employs MD simulations to investigate the tensile response to uniaxial deformation in various cellulose-sucrose systems. Tensile-strength simulations were conducted across a range of temperatures within the system. Notably, cellulose-sucrose systems with higher sucrose concentrations exhibit more pronounced changes in stiffness properties as temperatures increase from 300 K and beyond.*

Keywords: *#MDsimulation, cellulose-sucrose system, tensile-strength simulation, textile handling, finishes, sewing automation.*

1. INTRODUCTION

Over the years, the industrial system has undergone several transformative phases commonly referred to as "industrial revolutions." These revolutions marked the shift from manual craftsmanship to mechanized production, accompanied by the transition from small-scale operations to the emergence of large factories [1].

Each industrial revolution has ushered in new opportunities and advantages. Presently, automation stands as a valuable tool, evolving alongside technological innovations, offering substantial market potential for increased automation and the subsequent boost in productivity.

The term "*fourth industrial revolution*" was first introduced in Hannover in 2011[2], within the context of "Factories 4.0." Industry 4.0 embodies an organizational framework [3] designed to streamline the production of goods and services through integrated industrial platforms and digital technologies, which were previously employed separately [1].

The functionality of the industrial system is chiefly demonstrated through the production system, which plays a pivotal role in transforming raw materials into higher-value products. The manufacturing system, a subset of the production system, handles material processing, assembly, and the preparation of components to create products ready for the market. In modern manufacturing, some sectors can be automated or computerized to enhance efficiency.

Simulation is essential in digital manufacturing, providing valuable tools for testing and validating designs. It is particularly important in today's dynamic manufacturing landscape, marked by global trends like globalization and the growing demand for customized products.

Cotton, a naturally occurring fibre, is one of the most vital textile fibres utilized in the textile industry. In the natural world, a diverse range of polymers can be found, with cellulose being particularly abundant. Botanically, cotton plants belong to the Malvaceae family and the Gossypium genus [4], composed primarily of cellulose units with a 1,4-D-glucopyranose structure. The cellulose content in cotton plants can fluctuate, typically making up around 90% of the plant's composition. Through processes such as ginning and mechanical cleaning [5], the cotton fibres can be refined to contain roughly 95% cellulose, with other components like proteins, organic acids, amino acids, and more being removed through subsequent treatments. These treatments are designed to eliminate non-cellulosic materials, ultimately resulting in cotton fibres with approximately 99% cellulose content [6].

Figure 1 supplies a hierarchical structure of a generic plant depiction. The cellulose microfibril (labelled as "4") is a part of the plant cell wall (depicted as "3"), alongside hemicellulose (in blue lines) and lignin (represented in red lines).

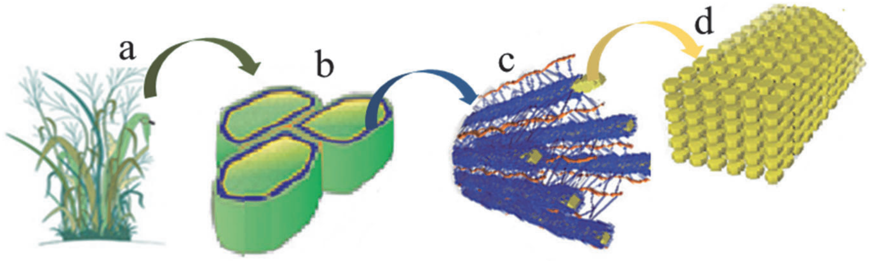

Figure 1. The hierarchical plant arrangement involves the presence of cellulose in the shape of micro-fibrils, comprised of aligned chains, as follows: a - the overall vegetal; b - individual vegetal cells; c - the vegetal cell wall and d - the cellulose microfibril (modified version according to reference [7]).

In the latter half of the 1950s, the first study on modelling dynamic molecular behavior through computer-based MD simulations was published and since then those type of simulations have demonstrated their versatility as a valuable tool for improving our comprehension of MD at the atomic level. It's essential to highlight that the field of MD-based computational modelling is continually advancing.

Utilizing the MD methodology allows for the simulation of experiments, shedding light on microscopic intricacies and offering additional insights into experimental outcomes whenever feasible [7]. MD simulations serve as computer-based methods employed to examine time-dependent behaviour and interactions of atoms and molecules. They find applications in the exploration of the characteristics and dynamics of diverse systems, including but not limited to cellulose-sucrose systems.

Sucrose is a common disaccharide composed of glucose and fructose molecules. Sucrose has a wide assortment of uses, and textile finishing is one of its uses to enhance the properties of fabrics. Using sucrose as a natural resource in textile finishing to create an environmentally friendly crosslinker is considered a cost-effective and eco-friendly alternative to some synthetic chemicals. This approach is particularly useful when aiming to replace traditional durable-press finishing agents in cotton fabric treatment [8]. Many sucrose-based derivatives are biodegradable, which can be beneficial in reducing the environmental impact of textile finishing processes.

Molecular dynamics (MD) simulations are experiencing growing utilization within the textile industry as a means to acquire a deeper understanding of the molecular-level behaviour of fibres, fabrics, and other textile materials. MD simulations have the potential to offer valuable insights into the textile sector, particularly in the domains of fibre structure and characteristics, interactions between fibres and polymers, as well as surface functionalization.

This paper utilizes both molecular dynamics (MD) simulations and experimental analysis to examine the response of cellulose-sucrose systems to uniaxial deformation. In fabric deformation experiments, the fabric displayed greater deformation in the warp direction. In MD simulations focusing on tensile strength, the study covered a temperature range within the system. It was observed that systems with higher sucrose concentrations exhibited more pronounced changes in stiffness properties as temperatures increased from ambient temperature to higher.

2. EXPERIMENTAL PART

MD methods

Molecular Dynamics (MD) simulations offer a means to attain a more thorough comprehension of the characteristics of textiles from a molecular perspective. This grasp holds the potential to drive the advancing frontier of textile material technology across diverse requisitions, covering a spectrum from apparel to textiles for medical, geotechnical or technical applications.

In molecular dynamics (MD) simulations, a molecule is represented as a series of charged points (atoms) linked together by springs (bonds). A force field, consisting of a collection of equations and related constants, is created to mimic the molecular geometry and specific attributes of the structures under investigation. The force field functions as an instrument to calculate bond lengths, bond angles, torsions, and non-bonding van der Waals and electrostatic interactions between atoms, which change as time goes on.

To investigate the dynamic behaviour of cellulose, MD simulations were applied at varying temperatures (300 K, 330 K, and 360 K) and using sucrose content ranging from 10% to 37.5%. Computerized simulations using molecular dynamics proved to be an invaluable method for comprehending cellulose[9], particularly its crystalline structure and its interactions with sucrose molecules under changing temperature conditions.

The general outline of how the MD simulations for cellulose-sucrose systems were set up and performed is as follows [6]:

i. The molecular structures of cellulose and sucrose were acquired using the research sources: cellulose [10] and sucrose [11]. The initial **system configuration** was created by arranging cellulose and sucrose molecules appropriately. Peculiarly, a rectangular box measuring 10.8 x 12 x 20.4 nm was generated. Introduce a cellulose fibre spanning 4320 residues into the box, aligning its longest side along the z-axis. The cellulose fibre, a parallelepiped, features a rectangular base on the xy plane with side lengths of 5.4 x 3 nm and a height of 20.4 nm along the z-direction. The cellulose fibre was centred within the simulation box, and surrounded by water or water and sucrose molecules. The number of sucrose molecules was selected to achieve the desired sucrose concentration.
ii. Opt for a suitable force field that accurately captures the interactions among the atoms within the system. Well-established **force fields** designed for carbohydrates and sugars are readily accessible in widely-used molecular simulation software such as GROMACS or CHARMM. In this study, the MARTINI force field was employed [12], with the cellulose and sucrose topologies acquired from [10]and [11], accordingly. A suitable force field for characterizing the atom interactions within the system was selected. Established force fields for carbohydrates and sugars are accessible in widely used MD software applications such as GROMACS or CHARMM. The MARTINI force field was employed for this work, as detailed in reference [12], with specific cellulose and sucrose topologies acquired from references [10] and [11] respectively.
iii. Heretofore initiating the simulation, an **energy minimization** procedure was conducted to refine the initial configuration and alleviate any unfavourable atomic clashes or overlaps.
iv. To prepare the system for productive executions, a sequence of **equilibration** stages was undertaken. An NPT equilibration was conducted (constant Number of particles, Pressure, and Temperature), employing a V-rescale thermostat to regulate temperature (with a 1 ps relaxation time) and a Berendsen barostat to maintain pressure at 1 bar (with a 12 ps relaxation time) [13]. The NPT equilibration stage lasted 2 ns, utilizing a time step of 20 fs. Coulombic interactions employed a reaction-field scheme [14] with a 1.1 nm truncation, while Lennard-Jones interactions utilized a 1.1 nm cut-off [15].
v. Following the equilibration phase, the production molecular dynamics (MD) simulation was conducted for an adequate duration to gather purposeful data. The **production run** extended throughout 300 nanoseconds, employing a time step of 30 femtoseconds. Coulombic

interactions were managed using a reaction-field scheme with a 1.1-nanometer truncation[14], and Lennard-Jones interactions were subjected to a cut-off of 1.1 nanometers. Temperature control was achieved through the application of the V-rescale thermostat, which featured a relaxation time of 1 picosecond, while pressure was maintained at 1 bar using the Parrinello-Rahman barostat [16] with a relaxation time of 12 picoseconds.

vi. Utilize molecular **visualization** software such as VMD or PyMOL to depict simulation trajectories and structural data, which aids in gaining a visual comprehension of molecular interactions and dynamics.

Young modulus

The investigation of elastic responses was carried out by applying a constant force at the endpoints of the model cellulose-sucrose systems, as shown in Figure 2. This force was oriented along two opposing directions parallel to the fibril axes. The magnitude of the applied force ranged from 0 to 6500 kJ $mol^{-1}nm^{-1}$, with intervals at 1300, 2600, 3900, and 6500 kJ $mol^{-1}nm^{-1}$.

To convert the applied force into stress, it was divided by the cross-sectional area of the fibrils, a value calculated based on the unit cell's dimensions and the number of chains. The strain under each applied force was determined as $\varepsilon = (L - L_0)/L_0$, where L_0 represents the initial length assessed between the centres of mass of both ends.

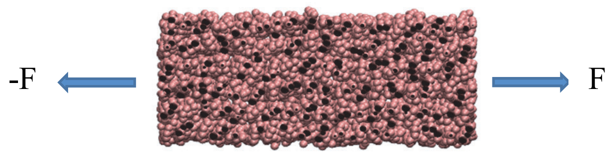

Figure 2. A cellulose model system that includes information about the method of applying an external force.

3. RESULTS AND DISCUSSION

3.1. The tensile stress-strain

Tensile stress-strain testing is a common approach for studying how textiles respond to stretching forces. This test helps determine a fabric's breaking load and elongation in both warp and weft directions. The results are influenced by factors like yarn type, fabric geometry, and structure. Mechanical analysis of textiles aims to understand their physical properties and their ability to withstand stretching and pulling forces, known as tensile strength. Tensile tests were performed using an Instron 3366 mechanical testing system. The Young modulus (or initial modulus) indicates a material's stiffness (high values) or softness (low values) under minor stress. The study investigates how different solutions affect the mechanical behaviour of textile [17] structures, including the specified sample sizes and process conditions in full detail in Table 1.

Table 1

The sample size and the configuration of the process used for conducting mechanical tests.

Fabric type	Length (mm)	Width (mm)	Speed (mm/min)	Temperature
Weave structure	60	20	10	Ambient temperature

The initial modulus plays a pivotal role in defining a fabric's texture. A greater initial modulus signifies a firmer and less pliable texture, whereas a lower initial modulus conveys a gentler and more adaptable feel. This characteristic is fundamental in comprehending how a fabric reacts to external forces. Figure 3 displays Young modulus results for a 100% cotton fabric. This figure provides insights into how different treatments affect the fabric's mechanical properties.

Both the tensile characteristics of structures are impacted by the attributes of the yarn and the structure of the fabric [18]. Experimentally observed (Figure 3) the fabric demonstrates more significant deformation along the warp path. When treated using a 10% sucrose concentration, there is a 13% augmentation in the ability of the fabric to deform while using a 37.5% sucrose concentration results in a significant 97% enhancement in the deformability of the structures [6].

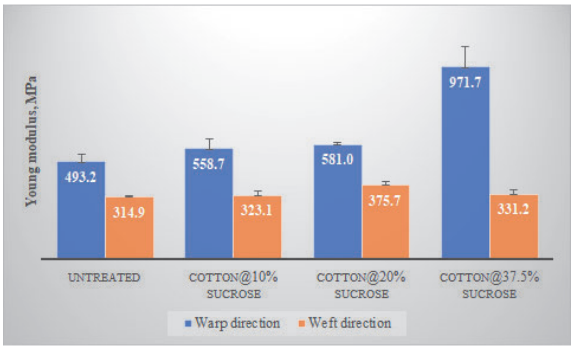

Figure 3. Young modulus results for cotton structures in both untreated (NT) and treated states.

3.2. Elastic modulus of cellulose-sucrose systems

The Young's modulus of elasticity was determined through a linear regression analysis conducted on the simulated stress-strain curves (as shown in Figure 4) where curves depicting the relationship between stress (σ) and strain (ε) were plotted for untreated (NT - cellulose system) and treated samples with 10%, 20%, and 37.5% cellulose-sucrose systems at temperatures of 300K (a), 330K (b), and 360K (c).

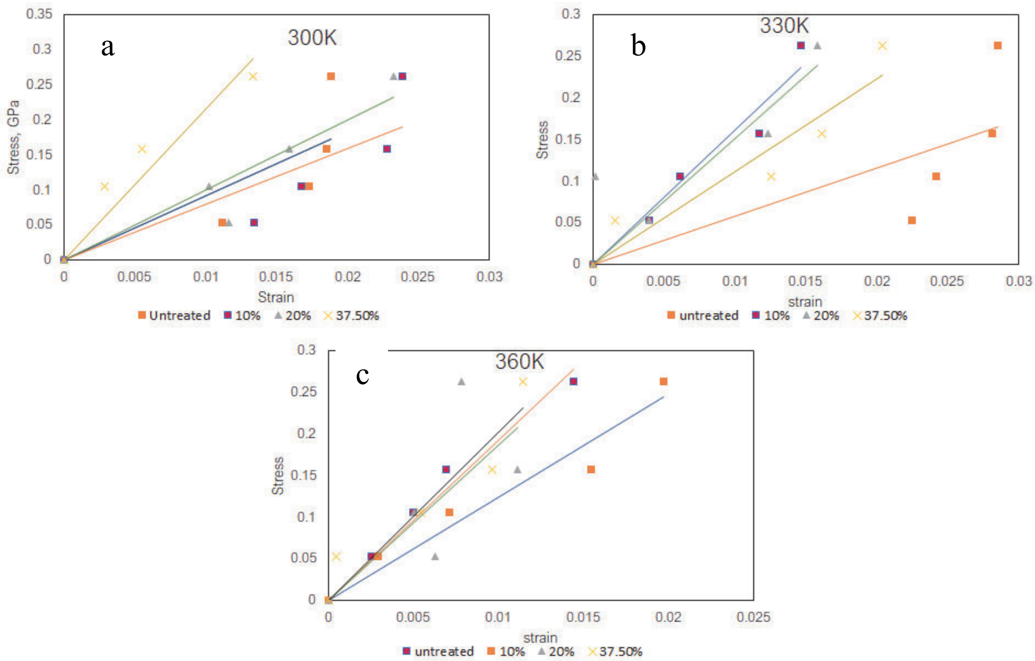

Figure 4. Stress (σ) versus strain (ε) curves plotted regarding untreated (NT - cellulose system) and treated (10%, 20%, and 37.5% cellulose-sucrose systems) samples simulated a 300K (a), 330K (b) and 360K (c) temperatures.

From Figure 4 can be observed how the temperature affects the cellulose-sucrose system behaviour. In particular, at 360K the influence of the sucrose component diminished.

4. CONCLUSIONS

This study employs MD simulations and experimental analysis to investigate the tensile response to uniaxial deformation in various cellulose-sucrose systems. In conclusion regarding fabric deformation experiments, - the fabric tested demonstrated more significant deformation along the warp direction; - treating the fabric at 10% resulted in a 13% increase in fabric deformability and - treating the fabric at 37.5% led to a considerable 97% enhancement in ability to deform of the structures while regarding MD Simulations for Tensile Strength can be noticed - MD simulations were conducted to study the tensile strength of cellulose-sucrose systems; - the simulations covered a range of temperatures within the system and - it was observed that systems with higher sucrose concentrations exhibited more pronounced changes in stiffness properties as temperatures increased from 300 K and additional.

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CONSIDERATIONS REGARDING THE INFLUENCE OF MATERIAL PROPERTIES ON THE GEOMETRY OF THE GARMENTS PATTERNS

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Abstract. *Sustainable fashion includes reducing carbon emissions, overproduction and pollution, protecting biodiversity and ensuring safe working conditions for garment workers. The designers and all the key stakeholders in this industry are aware of the problems of society and are trying to implement new solutions to transform this industry into a sustainable one: multifunctional design, eco-friendly materials and recycled fabrics, environmentally friendly treatment and dyeing technologies (GOTS certification guarantees the highest standard), reducing textile waste, recycling garments and turning them into vintage pieces, etc. In this industry, garments are still made traditionally: garment pieces are cut from textile materials, sewn and finished, so each step of the manufacturing process must be well executed to obtain a high-quality garment model. During the ironing stages of the manufacturing process, the shape of the garment pieces (a closed contour of straight and curved lines) can change due to the shrinkage properties of the textile materials (the garment may take on an uncomfortable shape and become scrap or waste). If this property of textile materials has high values, it must be considered when designing patterns for fitted garments, particularly in areas that significantly influence wearing comfort (e.g. armholes in fitted garments with shoulder support). This paper presents the influence of fabric shrinkage for a fitted jacket on the area that affects the appearance of the garment and the comfort of the wearer (armhole and sleeve head). These results are part of ongoing research on the topic mentioned as the title of this paper.*

Keywords: *patterns shape, materials properties, outline geometry, armhole.*

1. INTRODUCTION

The fashion and clothing industry is a dynamic sector which has to deal with complex problems generated by manufacturing processes (diversity of raw materials and accessories, diversity of types of equipment and fabrication stages), the use and potential depletion of different resources (water, energy, chemicals, etc.,), costs of the labour force, consumer behaviour and demands (personalised and diversified items at affordable prices, with a high level of quality, a short time delivery), competition among producers and environmental problems (waste management, limited raw materials reserves, pollution, emissions of CO2, etc) [1,2].

Among all the problems mentioned before, consumer behaviour and desires is a complex one because customer preferences and needs cannot be controlled or managed. According to their professional activities, habits, level of education, financial resources, and type of activities in which they are involved, their preferences are rapidly changed in terms of model style, provider, price and purchasing time [2,4].

The pandemic period, the Ukrainian war, and financial and political crises determined significant changes in everybody's lifestyle: we are more careful in choosing the items we want to buy, and we are looking for high-quality products that last a long time at an affordable price, that can be delivered in a short time to our homes. During the pandemic time, the habits of all humanity changed: we had to purchase different items from nearby stores or online platforms, carry out professional activities online, and maintain human connections in the virtual space.

Online activities (professional, entertainment or shopping) have completely changed consumer behaviour and how a product is purchased. The customer searches for the desired product/model on different platforms from the comfort of their home, chooses the source/platform that offers the best solutions and goes through the necessary steps to complete the action [6÷8].

On the other hand, in order to keep the customer connected and engaged in the virtual space, IT solution providers have developed various applications (also for smartphones) that enable users to access it [7,11]. Virtual fitting is one of the latest online applications used for selling clothing products, developed in different variants. Through these applications, the customer can check the fit of the chosen model on their virtual body and may change some of the stylistic details (material type, colour, length, decorative elements), and personalise it according to their wishes for purchasing. Applications based on virtual or augmented reality allow the designer to create a virtual 3D prototype of the garment, test different combinations of textile materials (diversify the model) and check whether the model fits nicely on the virtual mannequin (customer avatar).

Textile materials (fabrics) have different physical properties, and some must be considered when designing the shape of the main elements [4,5,8,9] because they may change the shape of the piece/ final garment negatively. The shrinkage property of textile fabrics is one of the physical properties usually considered in the marker model; if the shrinkage fabric is a high value, this must be considered in the design scenario, especially for fitted garments. This paper presents the influence of fabric shrinkage for a fitted jacket on the area that affects the appearance of the garment and the comfort of the wearer (armhole and sleeve head). This study belongs to ongoing research on the topic mentioned in the title of this paper.

2. METHODOLOGICAL APPROACH

Garments are characterised by various shapes and dimensions (inside and out) that differ from the shape of the human body, even in the case of fitted products. The shape and dimensions of the clothing product must meet the requirements of the user: ensure a high level of comfort, be well-balanced on the body and fit into the stylistic trends of the period in which it was produced [3].

The garment quality is directly influenced by the properties of the material, the shape and the size of the garment pieces, as well as by the manufacturing and finishing technology. During the design process, the user has to analyse the details of the model details and encode them into dimensional parameters, which have to be used in the design process, select the necessary materials (fabrics) and accessories, and to finally, design the shape and size of the garment pieces [10]. Through colour, design ratio, finishing treatments, and, last but not least, physical-mechanical properties (thickness, absolute and relative elongation (warp and weft directions), elasticity, contraction, spatial modelling capacity, stiffness, flexibility and draping capacity), the textile fabric influences the appearance and properties of the new product.

The manufacturing process for multilayer garments includes intermediate ironing phases or bonding, either for spatial modelling or pre-forming. If the model is going to be made of textiles that have higher shrinkage values (in warp and weft directions), a special category of allowances must be added in addition to the constructive allowances when designing the shape of the product elements/parts, in order to compensate for the changes in dimension during the intermediate ironing processes or bonding [7,10,12].

The following relations are used in order to determine the values of these allowances [3]:

$$A_{tutLi} = \frac{C'_u}{L_i} * 100 \tag{1}$$

$$A_{tutli} = \frac{C'_b}{l_i} * 100 \tag{2}$$

where: A_{tutLi} and A_{tutli} are allowances for compensating the material shrinkage on warp and weft directions, [cm]

C'_u and C'_b are the determined shrinkage values, [%]

L_i and l_i represent the length of the longitudinal and transversal constructive segments, [cm]

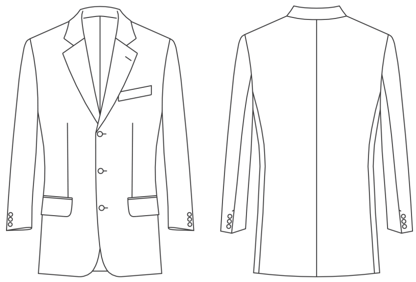
$$C'_u = C_u * 50\% \tag{3}$$

$$C'_b = C_b * 50\% \tag{4}$$

where: C_u is the shrinkage value on warp direction, [%]

C_b is the shrinkage value on weft direction, [%].

For this study, it has been chosen a classic male jacket (see figure 1). The details of the model are: the top has lapels and a collar and closes with a single row of buttons. The model has two flap pockets below the waist and a loop pocket on the top of the left side.



(a) (b)

Figure 1. Jacket model: (a) Front, (b) Back

The model was designed with a bust allowance value of 8.5 cm, for a material with a 1% shrinkage value for both the warp and weft directions. The design process consisted of the following stages: elaborating the design solution according to the details of the model and the shape of the human body; determining the values of the necessary parameters; computing the values of the main constructive segments and finally, designing the shape of the main elements (the patterns were designed using Lectra software- Modaris V8, see figure 2) [3,12,13]. When the same model was made from other textile materials (with different shrinkage properties than to the reference material), some fitting problems (tensions) were observed on the dressed mannequin (back, armhole and front areas). Under these conditions, it was necessary to change the structure of the mathematical relationships that determine the level of the depth line of the product and the width of the main elements by taking into account the values of the allowances for compensating the material shrinkage in the warp and weft directions.

The general structure of the constructive segments, which have a decisive influence on the appearance of the garment on the body and its balance, is as follows [3]:

$$\text{Back height}= f(a_1{*}Pb,\ A_{\ell i1},\ A_{tutLi}) \tag{5}$$

$$\text{Back width}=f(a_2{*}Pb,\ A_{\ell i2},\ s{*}A_b,\ A_{tutli}) \tag{6}$$

$$\text{Side panel width}=f(a_3{*}Pb,\ A_{\ell i3},\ m{*}A_b,\ A_{tutli}) \tag{7}$$

$$\text{Front width}= f(a_4{*}Pb,\ A_{\ell i4},\ f{*}A_b,\ A_{tutli}) \tag{8}$$

where: $a_1 \div a_4$ are the proportional coefficients between the circumference of the bust (Pb) and the secondary body dimensions, which correspond to the constructive segment that we want to assess;

$A_{\ell i1} \div A_{\ell i4}$ represent the values of the allowances which ensure the freedom of movement for the movement (when clothed);

s,m and f are the distribution coefficients of the bust allowances in the back, side panel and front;

A_{tutLi}, A_{tutli} are allowances whose purpose is to compensate the material shrinkage in the warp and weft directions.

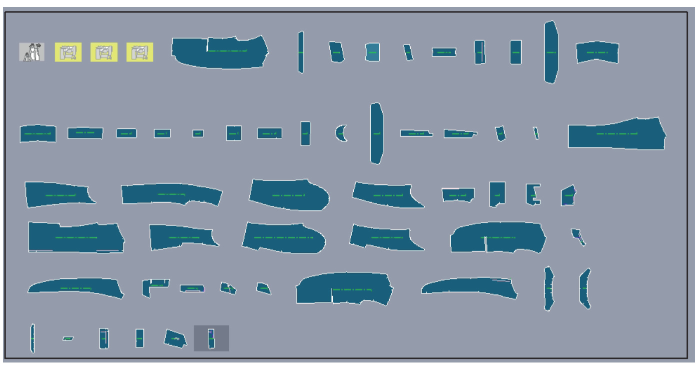


Figure 2. Jacket components

The designer drafts the shapes of all the necessary components. He then examined the width of the main elements (in-depth, at waist and hip level), the shape and length of the contour line for the components sewn together, the position of the notch points between the aforementioned components, the length of the sleeve head in relation to the armhole length and the final shape of the respective virtual prototype made for each type of material.

For this type of product, the position, shape and the size of the sleeve are very important; the width of the side component directly influences the sleeve width and wearing comfort; the sleeve height is directly influenced by the armhole height, and the length of the sleeve head is directly determined by the length of the armhole. The armhole is also known to be an area with curved lines whose shape is determined by the human posture (see figure 3).

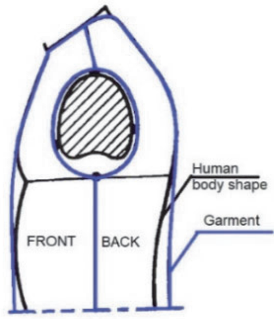


Figure 3. Garment armhole (general representation)

Based on our previous discussion, the product areas where the influence of the shrinkage properties of textile fabrics must be analysed are the armhole and the contour line of the sleeve head. Under these circumstances, the methodology approach was developed as follows:

a) Designing the shape of the main elements of the jacket (see figure 1) for size 50 (Pb=100 cm) and for a textile fabric with 1% shrinkage value (weft and warp directions). Design the same model, taking into account the mathematical relationships 5÷8, for other textile materials that have different shrinkage values in the warp and weft directions (listed in table 1);
b) Evaluating the shape and the length of the contour lines of the pieces which are sewn together;
c) Measuring the length of the armhole and the length of the sleeve head (for all the materials);
d) Determine the fabric consumption and the value of the index utilisation (complementary result).

The results (c and d) are presented in table 1. The result (c) is relevant to the topic of the paper.

Table 1.

Values of constructive parameters. Fabric consumption and utilisation index values

Fabrics shrinkage values (warp and weft directions) [%]		**The length of the armhole [cm]**			**The length of the sleeve head [cm]**		**Fabric consumption (fabric width =125cm) [m/item]**	**Value of index utilisation [%]**
Warp	Weft	Front	Side panel	Back	Front	Back		
1 (reference)	1 (reference)	25.11	17.76	18.08	39.97	26.98	2.17	70.13
3.6	1	25.27	17.80	18.18	40.63	26.37	2.23	70.87
4.5	5.5	25.77	17.67	18.23	40.59	25.37	2.3	72.28
5	3	25.35	17.29	17.92	40.62	25.43	2.32	70.66
7	4.5	25.65	17.92	18.35	40.56	26.73	2.37	70.88
4.5	6	25.89	17.62	18.37	40.5	25.58	2.34	72.2
6	3.5	25.40	17.32	17.90	40.47	26.89	2.28	70.53
8	5.5	25.77	18.1	18.47	40.62	26.64	2.28	70.68
6.5	2.5	25.48	17.35	17.98	40.43	25.47	2.35	70.48
2.5	5	25.12	17.82	18.25	40.03	17.02	2.19	70.23

3. RESULTS AND DISCUSSION

Based on the analysis from table 1, the following conclusions can be drawn:

- the values of the fabric shrinkage directly influence the values of the constructive parameters; if the latter are higher, then the values of the constructive parameters are also higher compared with the reference item;
- higher values of fabric shrinkage along the warp directions have a significant impact on the sleeve lengths, especially on the back (the head of the back sleeve has a pronounced concave shape);
- higher values of fabric shrinkage along the weft direction have a significant impact on the width of front, back and side components;
- higher values of fabric shrinkage along the warp direction increase the value of specific consumption;
- higher values of fabric shrinkage along the weft direction increase the value of fabric index utilisation;
- if the difference between the shrinkage values along the weft and warp direction is less than two units, their influence on the values of the constructive parameters is moderate.

By analysing the shapes of the model parts made for the reference material (with 1% shrinkage values on warp and weft directions), the designer can identify what changes to make, what percentage of the shrinkage value needs to be taken into account during the design phase of the garment piece, and what proportion must be considered when designing the production patterns (determining the values for the technological allowances) and when making markers.

Table 1 also shows the values of fabric consumption and index utilisation; as is well known, when the shrinkage values increase, the fabric consumption also increases. The results from table 1 show that the influence of the difference between the shrinkage values in the weft and warp direction is less than two units; its influence on the values for the fabric consumption and the fabric utilisation index is moderate.

4. CONCLUSIONS

The physical properties of textile fabrics influence the final appearance of the new product, as well as its dimensions, the fabric usage percentage, and its final price. Ensuring the quality of the new model is a process that begins with carefully choosing the necessary fabrics and accessories. Textile fabrics are characterised by different properties which determine: the changes in the shape and size of the material (due to shrinkage, as well as its elasticity and stretch properties), drapeability (due to its density, design ratio, thickness, types of fibres, etc.), and specific mass. These properties must be taken into account during all stages of product development, as they influence the appearance of the new product, the parameters of the technological manufacturing process, the quality, the price, the life cycle and the degree of the wearer's satisfaction.

This paper investigated the influence of fabric shrinkage properties on different constructive parameters that play a significant role in the comfort of the wearer. For garments that are supported on the shoulder area (fitted models), the width of the main elements on the depth level is crucial: the correct values for the width determine the degree of freedom of movement of the arms, the one of the back of the garment at the level of the shoulder blade, the degree of comfort when breathing or moving, and last but not least, a good appearance of the garment on the body. The shrinkage value of the textile fabric is determined along the warp and weft directions (perpendicular orientation); for constructive parameters that have the same orientation as the warp and weft directions of the fabric, the influence of the fabric shrinkage is clear (higher values of shrinkage determine higher values for the constructive parameters of the garment in the warp/weft direction); for the curve contour lines with different orientations with respect to the warp and weft directions, the influence of the shrinkage values is slightly more complex, as the shape and length of the contour lines are influenced by the angle at which they lie in the warp and weft directions (if these lines are closer to the warp direction, the shrinkage value in this direction has a more significant influence than the one corresponding to the weft direction).

If the contour line is longer, its dependence on the value of the shrinkage is also more significant than for short lines. We must emphasise that the data on the values of the shrinkage allowances for different types of fabrics must be considered during the design process in the mathematical relations used to determine the values of the important constructive segments.

This paper presents partial results of an ongoing study on the influence of material properties on the geometry of patterns for various garments. The results obtained in this study will be used in the development of garment blocks for different fitted garments and textile fabrics. It would also be interesting to study the tension map (stress area) of the virtual prototype of the model for avatars corresponding to different wearers (whose bodies have different proportions, postures, and conformations) in order to determine whether the garment is well-balanced, if it is esthetically acceptable, and if the types of fabrics have been well matched.

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DIGITAL FASHION – A MUST IN OUR DAYS

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***Abstract**. Digital fashion answers to three major challenges of the present: digitalization, sustainability and access of people with disabilities. Digitalization is an actual issue, its importance being emphasized during the pandemic crisis. Digitalization in the fashion field will help the designers and will allow the transition to 4.0 fashion industry. In the mean time, by using a digital platform, knowledge data base and a virtual simulation of the product, the need of a physical prototype is eliminated and also allows the on-line communication between designers, clients and producers, so that there is no need for face to face meetings, saving the traveling costs and polution. This is supporting the sustainability issue, an important topic for the fashion industry as it is a well known fact that the textile and clothing industry is one of the great poluters. It is common knowledge that digital solutions are essential for those with various types of disability. The digital fashion platform and textile material library developed in the frame of the project Erasmus+, Digital Fashion, 2021-1-RO01-KA220-HED-000031150 will be presented in this paper. In order to fulfill the main objective of the project, four project results were take into consideration, starting with a survey about the digitalization level in fashion companies and ending with the learning posibilities for the students, designers and employees of the fashion industry.*

***Keywords:** Erasmus project, digitalization, survey, on-line platform.*

1. INTRODUCTION

The digitalization process is one of the actual trends in all the major fields of activity. In 2015, the European Commission launched the initiative "A Digital Agenda for Europe" as part of the Europe 2020 Strategy (European Court of Auditors Report, 2020), which was designed to create a Digital Single Market with positive effects on a sustainable economy and society. As an immediate and complementary effect, the European Commission launched in 2016 the European industry digitisation initiative using the term digital transformation in an industrial context.

The pandemic problem has aided in hastening the progress of digitalization. As face-to-face comunication was seriously restricted, the digital solutions forced the fashion industry to evoluate towards 4.0 industry level, the only possible way for avoiding a general economic collapse.

According to Digital Economy and Society Index [1] (DESI - 2022), a global indicator calculated according to human resources, connectivity, digital technology integration and digital public services, Romania is situated on the last place among the states member of the EU. From the four field of DESI index, only the connectivity in Romania is a strong point, this enabling the development of digital projects. From the human resources point of view, it can be acknowledged that Romania has a great potential, as the number of graduates with a degree in information and communication technology is 5.6% of all graduates, compared to the EU average of 3.6%, but yet the DESI index place Romania at the lowest level. This is the second strong motive for the development of the digitalization projects.

The fashion and particulary the textile and clothing industry can be characterised with a low level of digitalization, fact that was brought to light by the pandemic crisis. The digitisation of economic and administrative sectors and companies is a priority for the Romanian Government, with numerous funding programmes (PNRR, POCIDIF) dedicated to this objective, another strong point for the digitalization projects.

The fashion, namely textile and clothing industry, is well known as a very poluting industry and increasing the sustenability in these companies is a major issue at the European Comunity level. Using the digital solutions for the developers of the fashion comunity will help decreasing the negative impact upon environment, first by eliminating the need of a physical prototype and also by allowing on-line communication between designers, clients and producers, reducing the polution due to traveling activities. This is another strong point that validates the digitalization in the fashion sector.

Answering to the needs of both education field and fashion industry, the Erasmus+ project *Digital Fashion-Collaborative Online International Learning in Digital Fashion* [2], will be presented in this paper. The project is coordinated by the National Research and Development Institute for Textile and Leather from Romania (INCDTP), and has five other partners, namely: "Gheorghe Asachi" Technical University of Iasi – Romania (TUIasi), National Higher School of Arts and Textile Industries from France (ENSAIT), HOGENT University of Applied Sciences and Arts from Belgium, University of Maribor from Slovenia and Textile and Clothing Technological Center from Portugal (CITEVE). The project has started on February First 2022 and it will end after 36 month, being developed in the frame of European Commission's ERASMUS+, Strategic Partnerships for Higher Education.

In this project, the following issues are approched [2]:

- A new methodology for an international collaborative online learning framework in the field of digital fashion;
- Development of three database containing textile materials, garments models and patterns;
- On-line Digital Fashion platform dedicated to students, designers, people from fashion industry;
- Online curriculum based on the new collaborative online module in digital fashion that will include new training and assessment methodologies for fashion co-design.

As on all the Erasmus projects, one of the most important issue consists in the dissemination of the work done in the project.

The aim of the paper is to present the projects results, the work done so far and the future expectations.

2. METHODOLOGY

The first issue of the project was to justify the necessity of the digitalization in the fashion industry [3]. The results were obtained after a series of on-line survey and interviews conducted in all the partners' countries. The questions were aiming the level of digitalization, the human resource skills, the software used for specific field and further intentions on the fashion digitalization issue. Results from all sorts of fashion companies, small or big, developing garments under their one brand or working under multinational license, were collected.

The second issue of the project is the development of the DigitalFashion on-line platform and establishing the necessary curricula containing the required modules and the learning outcomes, so that the learners will be able to use the platform.

The platform is developed based on the knowledge and experience in the field of the partners.

3. RESULTS AND DISCUSSION

3.1. Using digital tools for fashion design in Romania

The results of the interiews [4] were collaborated with the results of a research made for a phD thesis [5] with a theme about the digital maturity of Romanian companies from fashion industry .

The use of virtual fashion systems is an element of differentiation between EU and Romanian companies, as 31% of EU companies have been using these systems for 20-25 years, 14% for 4-10 years, the Romanian companies have been using them for less than 3 years. A high percentage of the companies that do not yet use virtual fashion software intend to implement them in the near future (43% of EU companies and 45% of Romanian companies).

Another interesting result is focused on the sectors of product development in Romanian companies where the specialized software is used (figure 1). From this point of view the results colected from the Romanian companies are similar with the ones from the projects partners. For fashion design, over 60% EU companies and over 50% Romanian companies, are using digital tools; for technical drawings also the percentage is similar (70% EU companies and 65% Romanian companies), for 2D pattern design the percentage is higher in Romania (90%) comparing to the EU countries were the study was conducted (80%), while the 3D garment visualization is higher in EU (40%), comparing with 30% in Romania.

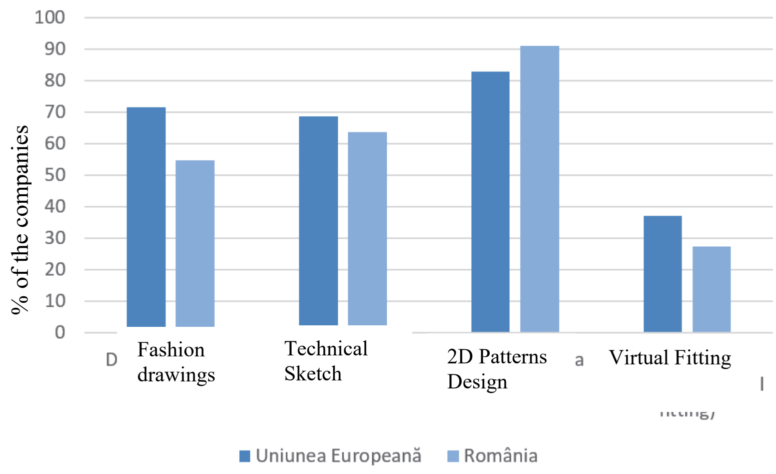

Figure 1. Using digital tools for product development

3.2. Digital fashion on-line platform

The outcome of the first project result of the project helped on developing the DigitalFashion on-line platform. The basic of platform's structure is presented in figure 2.

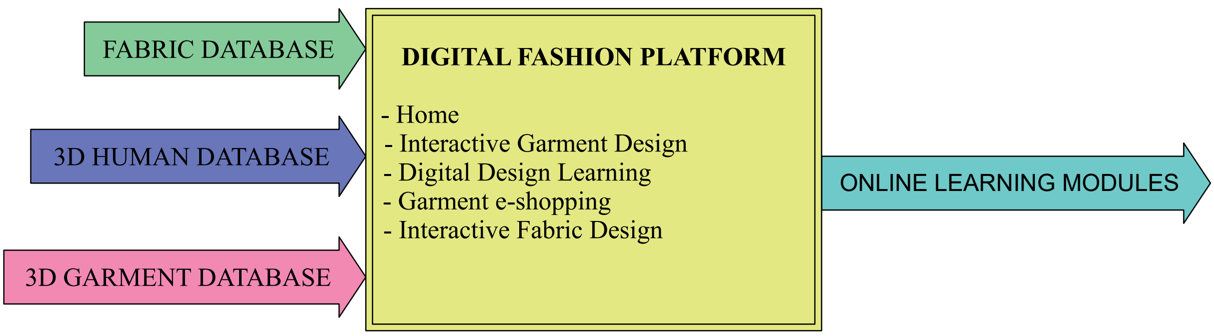

Figure 2. Principle of the DigitalFashion platform

In the home page of the DigitalFashion platform there are stated the four fundamental activities: garment design, fittting adjustment, knowledge base/ design learning, garment e-shoping.

On the page consisting of *interactive garment design* there will be displayed both a collection of 3D garments and some techical parameters, as body measures, fabric parameters, garment style and patterns.

Digital Design Learning has three main functions: knowledge base, virtual try-on, and digitalized fabric process. By using four fundamental garment types, it will be step by step demonstrate how a digital 3D garment can be recognized. The virtual try-on will consists of the follwing steps: digitalize fabric or choosing from the existing fabric data base, select the human avatar and a garment type. The achieved fitting result will lead to a virtual fitting image with the ease allowance effect (color map), pattern information, and material properties.

Based on this structure of the DigitalFashion platform it was possible to propose the content of the online learning modules. The first module will be an introduction in the project's oportunity and will answer to the following questions:

1. Why is Digital Fashion necessary?
2. Who will benefit? Is it possible for people with disabilities to follow the modules?
3. What will the platform facilitate?
4. What is the platform content?

Reading the introductive module, the learner will know if the platform is of interest for him and what will be able to do after completing each module.

The next modules can be developed following the platform structure, according with the aim of every component:

2. Fashion database
   2.1. Fashion requirements
   2.2. Concrete design elements
3. Fabric database
4. Garment database
   4.1. Design cases
   4.2. 2D / 3D garment design
5. Garment e-shopping

For each module the common and specific learning outcomes will be stated, study cases and demonstrations, exercises necessary for the learner to evaluate his or hers knowledge level.

4. CONCLUSIONS

The DigitalFshion project, developed in the frame of EC Programme Erasmus+, is of great actuality and it supports all the major themes established by the European Community. It answers to the need of digitalization, sustainability and people with disabilities access.

The project's content can be expanded to cover more facets of the textile and apparel industries, such as protective and technical equipment. The principle and the platform is the same, the difference being made by the data base content.

The on-line DigitalFashion platform can be an useful tool for students, designers, people from textile and clothing companies, as the Romanian fashion companies are prioritizing the digitalization process, according with the EU agenda.

Acknowledgements

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HACKTEX VIRTUAL TRAINING MATERIALS FOR SMART TEXTILES

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Abstract. *Smart textiles represent a domain in full development for the textile industry, with a huge potential of growing in the near future and attractive for young specialists due to better paid jobs. This perspective need for specialists with knowledge and skills tailored to the needs of the sector has to be met by the universities. The existing curricula at B.Sc. and M.Sc. levels of many universities do not cover or cover insufficiently these topics. The Erasmus + project HACKTEX prepared a set of virtual training materials on smart textiles and another one on entrepreneurship focusing on smart textiles that will ensure not only technical knowledge, but also will support the idea of transferring the acquired knowledge toward the market. They are addressed not only to textile students, but also to students in connected domains, related to the production and use of smart textiles. The virtual training materials on smart textiles discuss significant issues related to raw materials, technological processing, testing and standardization in the domain and sustainability. The materials are designed to be user friendly and prepared in video format and as reading materials, helping students and specialists wanting to learn more about the field understanding what is required to develop a functional smart textile product that can answer the needs of the customers. The materials for entrepreneurship are designed to be a map on what to consider when developing your own business with smart textiles, how to choose the best suited business model and what steps are required. A database with information on companies already on the market completes the training materials. A guide connecting all information is also provided.*

Keywords: *multidisciplinary engineering, lessons, video format, entrepreneurship.*

1. INTRODUCTION

The HACKTEX project is an ERASMUS+ project that aims to develop innovative tools for the digital era and facilitate distance learning for the complex applications characterizing smart textiles. The consortium is made up of universities, NGOs dedicated to education and a textile cluster from 6 EU countries.

The complex context of the HACKTEX project is defined by general economic conditions, as well as the changes brought by the SARSCOV-2 pandemic, that affected the textiles and clothing industry as well as higher education system. Apart from the challenges due to the competition from the emerging markets, the sector needs to be aligned with the new European industrial strategy and its targets – climate neutrality and digital leadership. The European Union requires reassessing its position on critical factors affecting its competitiveness, such as uniqueness of its products, workforce with highly specialized and transversal skills and innovation, in order to give the competitive advantages needed in the current global economy.

Advanced/smart/functionalized textile materials [1, 2, 3] are an emerging sector within the textile industry, driven by transdisciplinary innovation in several end-markets, focusing on the technical aspects and controlled functionality of textile materials rather than on the aesthetics, that answer these requirements. For its development, the sector needs to stimulate applied research and industrial exploitation of innovation. On the other hand, universities must support the development of the smart textiles sector, anticipating and ensuring the cross sectoral knowledge and specialized skills needed by the companies and fostering innovation in the field. These skills must respond to the transition toward Industry 4.0 principles, especially digitization and add the entrepreneurial dimension that is essential in bringing research to the industry and unlock the innovation potential of advanced textiles [4, 5]. While smart textiles became part of the curricula in the last decade, the domain has still untapped opportunities at manufacturing level as both drivers of textile digitalization and development of new niche markets. Professionals that will implement those transformations require a highly qualified education to become innovative game-changers for the sector supported by strong digital tools and virtual learning experience. Also, the academic activities were strongly affected by the pandemics, students that were usually hands-on learners both in textile engineering and textile design had to transfer to online theoretical and practical activities. The current limitations and social distancing require new tools to address the efficiency of engineering and entrepreneurial training, especially when considering the advantages demonstrated by online training that go beyond this situation: development of digital skills, flexibility in teaching and learning, remote access to knowledge, possibilities for direct contact of teachers and students with economic agents without additional costs and fostering durable innovative partnerships that can evolve into applied research projects, etc.

In this context, the HACKTEX consortium created a virtual course (MOOC) on smart textiles and a virtual guide on entrepreneurship focusing on smart textiles. These virtual training materials are designed to help students and young specialists from the textile sector, as well as other sectors connected to textiles through dedicated applications, to obtain knowledge related to smart textiles and to understand the requirements to develop an efficient and successful business model, so that the ideas developed through research can make the transition towards the market.

This paper presents and discusses the virtual training materials developed by the consortium, emphasising the purpose of the knowledge content for the learning units and lessons and the advantages of virtual training in the context of smart textiles.

2. VIRTUAL TRAINING MATERIALS (MOOC) FOR SMART TEXTILES

The content of the virtual training materials is organised in 5 learning units and is designed to cover all major issues related to smart textiles – raw materials, specific technologies, characterisation of smart textile materials and products. Sustainability is also considered and discussed, as its importance will increase over the next decade and the continuous innovation in the field will need to be adapted to sustainability principles [6]. An introduction in the field of smart textiles is provided in the beginning, as to help people that have little or no previous knowledge by explaining the fundamentals of smart textiles.

The learning units are divided into 3 lessons each, discussing the main aspects of the respective topic. The lessons are in a user friendly and accessible video format. For those who want to go further on a certain topic, reading materials are provided, with the information discussed in the video and with supplementary knowledge and recommendations for further reading. The structure of the training materials, learning units and lessons is illustrated in Figure 1.

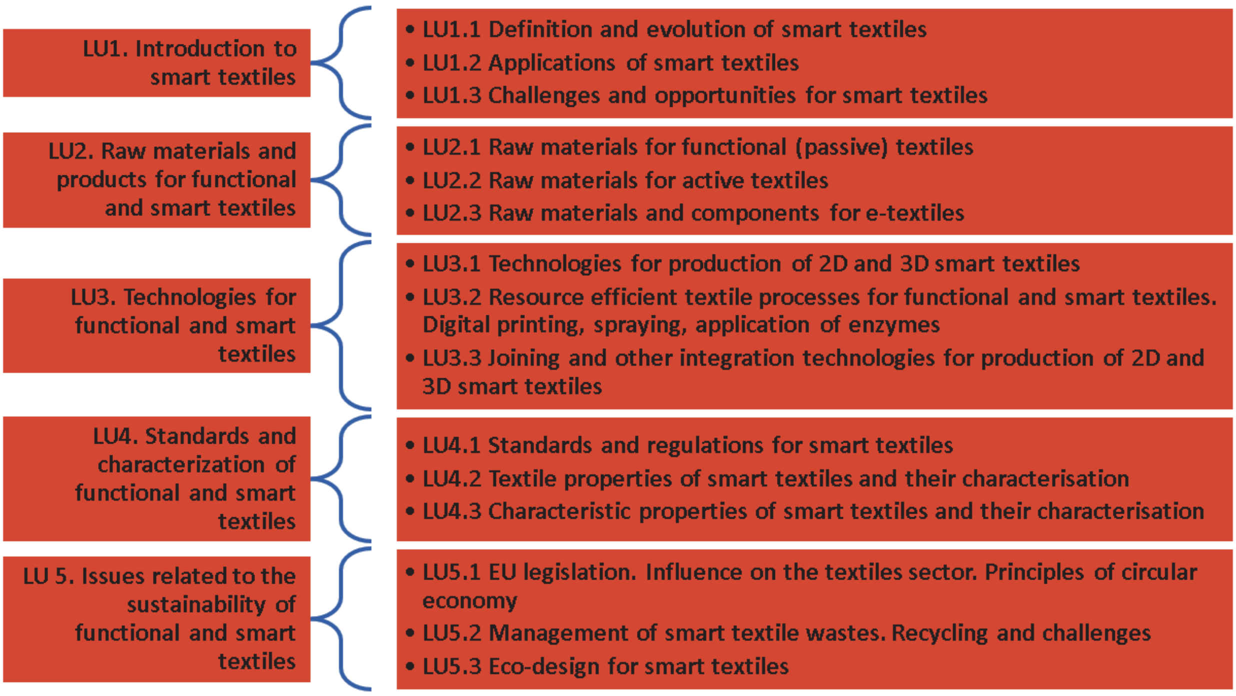

Figure 1. Structure of the virtual training materials on smart textiles

Each lesson is tailored to have specific outcomes related to smart textiles, as detailed in Table 1. These outcomes help the person taking the courses to understand fundamental knowledge regarding the domain and to use it to identify, select or use this information to develop smart textiles.

Table 1

Learning outcomes for the lessons of the learning units

Topics of the lessons	Learning outcomes
LU1 Introduction to smart textiles	
LU1.1 Definition and evolution of smart textiles	● Recognize and define the term smart textiles. ● Understand the subgroups and exhibit specific examples ● Identify important milestones
LU1.2 Applications of smart textiles	● Classify the main fields of applications of smart textiles ● Explain the scientific issues and propose solutions regarding various prototypes ● Developing products using the concept of smart textiles
LU1.3 Challenges and opportunities for smart textiles	● Recognize and outline the challenges facing smart textiles ● Breakdown the key challenges of smart textiles in terms of user experience, technology and critical factors. ● Identify the opportunities of smart textiles in different application areas.
LU2 Raw materials and components for functional and smart textiles	
LU2.1 Raw materials for functional (passive) textiles	● Recognize the main raw materials to develop functional (passive) textiles ● Classify the main raw materials by their smart functionalities ● Identify the type of raw material required to impart certain functionalities to textiles
LU2.2 Raw materials for active textiles	● Recognize the main raw materials to develop active smart textiles ● Classify the raw materials by their smart functionalities ● Identify the type of raw material required to impart certain smart functionalities to textiles
LU2.3 Raw materials and components for e-textiles	● Knowledge about specific fibres and their use in smart textile systems ● Understand the functions of various technology components and their applications in textiles ● Be familiar with a wearable technology system in everyday life
LU3 Technologies for functional and smart textiles	
LU3.1 Technologies for production of 2D and 3D smart textiles	● Acquire knowledge on the latest developments in textile technology suitable for the production of smart textiles ● Understand and compare the possibilities of each technology and select the one that can produce textiles with the required specifics ● Develop skills in designing textile materials/products with smart behaviour
LU3.2 Resource efficient textile processes for functional and smart textiles. Digital printing, spraying, application of enzymes	● Explain the existing problems and challenges in production of functional and smart textiles ● Classify different digital printing technologies ● Explain the printing mechanisms as well as spray technology ● Recognize the differences of conventional production methods with the resource-efficient ones. ● Classify the main fields of application of different resource-efficient technologies in textile research and industry
LU3.3 Joining and other integration technologies for production of 2D and 3D smart textiles	● Recognize the different integration techniques for design, development, and manufacturing of smart textiles. ● Differentiate among the principles as well as pros and cons of different integration techniques. ● Identify the best practices to produce smart textiles.

LU4 Standards and characterization of functional and smart textiles	
LU4.1 Standards and regulations for smart textiles	● Understand the importance of standards and their applicability in smart textiles ● Become familiarised with the organisations creating standards for smart textiles (EU and in the world) ● Understand what is required to make a standardised evaluation of a smart textile product
LU4.2 Textile properties of smart textiles and their characterisation	● Match textile properties with requirements for a determined smart application ● Differentiate the appropriate testing methods for the characterisation of textile properties ● Judge the importance of textile properties in smart applications
LU4.3 Characteristic properties of smart textiles and their characterisation	● Select the appropriate standard/s in connection to the type of application ● Understand the specificity of equipment and testing method/s required for testing smart textiles ● Develop knowledge related to the qualitative evaluation of smart textiles ● Develop skills for testing and evaluating smart textiles ● Develop skills to design and conduct an experimental program for the evaluation of smart textiles
LU5 Issues related to the sustainability of functional and smart textiles	
LU5.1 EU legislation. Influence on the textiles sector. Principles of circular economy	● Understand the reason of evolution of the latest legislation establishment in EU in textiles industry ● Understand the term circular economy and its importance in textiles industry ● Become familiar with related legislations
LU5.2 Management of smart textiles wastes. Recycling and challenges	● Knowledge about the cycle of life of an e-textile, the types of produced wastes and their recycling methods. ● Realise the importance of a sustainable management of the produced wastes during the life of a smart textile. ● Understand what sustainable waste management is and confront the challenges of the procedure.
LU5.3 Eco-design for smart textiles	● Identify potential sustainability weaknesses during the design phase of smart textiles ● Examine potential solutions to the potential sustainability weaknesses ● Use eco-design strategies for the development of smart textiles ● Assess the sustainability of smart textile products

3. VIRTUAL GUIDE FOR ENTREPRENEURSHIP FOCUSING ON SMART TEXTILES

The virtual guide for entrepreneurship is a useful tool to help students and young specialists to understand what is required to develop a successful business model and where to start from. The guide will offer students and other external users helpful tips and industrial challenges that need to be faced in the smart textiles sector.

The guide is based on 4 units developed by the consortium, lectures organised on the topics presented in Figure 2. As for the virtual training materials, the information is presented in video format, with reading materials attached, so that the users can access the written version, with proposals for further study on each subject. All videos make direct reference to smart textiles and how the specificities of the sector influence the decision-making process.

In order to give real-life examples of EU companies that develop smart textiles, supporting the knowledge presented in the 4 units, a database was created. It offers practical solutions for how business models are created for different types of companies.

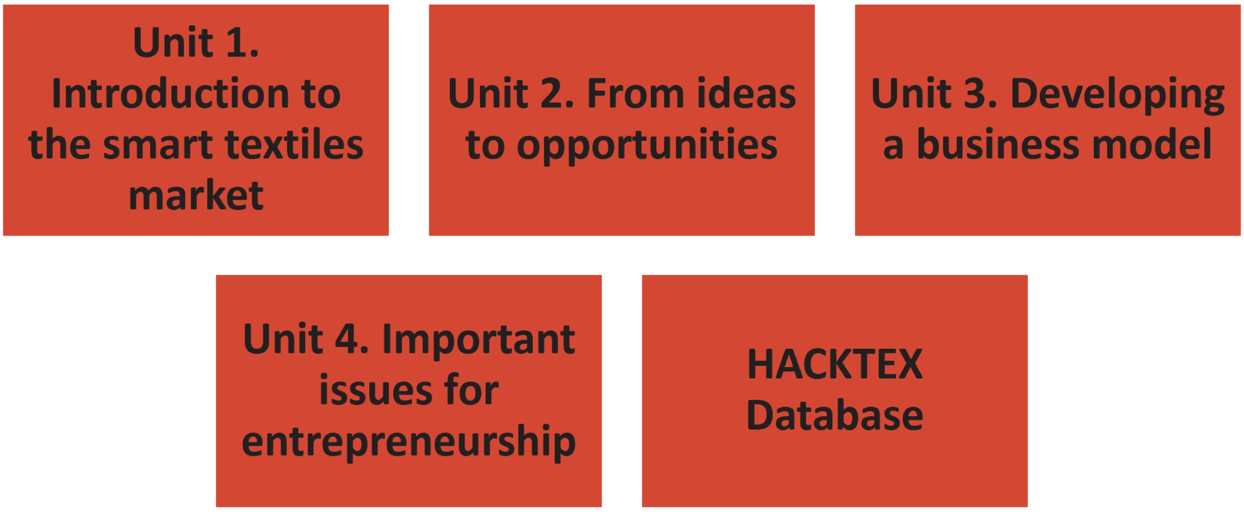

Figure 2. Topics for the knowledge related to the virtual guide on entrepreneurship

Unit 1. Introduction to the smart textiles market

This unit provides an overview of the situation and main trends and players in the smart textiles market, discussing specific supply chains, relevant manufacturing companies, and industries using smart textiles.

Unit 2. From ideas to opportunities

There is a lot of research done in the field of smart textiles, but few ideas make the transition toward the market. In this context, the unit will cover topics referring to various tools to understand and recognize unmet needs and market opportunities, methods and techniques used to develop and validate business ideas and how to recognise future market developments, opportunities and challenges.

Unit 3. Developing a business model

The users learn how to better understand the needs and behaviour of potential customers and create a value proposition for these customers. The unit also covers aspects regarding the activities and resources needed in order to develop the business and the marketing most suitable to be used in order to commercialise the company's products.

Unit 4. Important issues for entrepreneurship

This unit covers other aspects important for the success of an entrepreneurial endeavour, such as the process of designing a business pitch in order to find potential funding, tools to ensure business sustainability and how to choose the most suitable exit strategy. It discusses the concept of business strategy, the phases of a project, benefits of rules and responsibilities in a project, as well as concepts related to project management through the concept of games, market positioning in two steps and the BCG matrix approach.

3. CONCLUSIONS

The ERASMUS+ project HACKTEX aims to create efficient education tools to respond to the needs of the smart textile sector in terms of preparing specialists that have the anticipated skills to innovate and develop such products. Furthermore, currently, the results of research regarding smart textiles do not transition towards the market. Apart from technical consideration, one of the reasons for the existing situation is the lack of entrepreneurial education applied to the needs and requirements of the sector.

The paper presents the virtual training materials created by the HACKTEX consortium for smart textiles and for entrepreneurship in the field. The content of these materials is presented and discussed, explaining the topic selection and the expected outcomes for each lesson (for the MOOC).

Acknowledgements

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ENVIRONMENTAL INITIATIVES THROUGH GENDER-BASED TRAINING

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***Abstract**. In the past few decades, the EU has taken great strides towards gender equality. This is the outcome of laws mandating equal treatment, gender mainstreaming, and the consideration of gender as a factor in creating all other policies and taking special steps to support women. The main goals are to put an end to gender-based violence, fight against gender stereotypes, close the gender pay and pension gap, close the gender care gap, achieve equal participation in all economic sectors, and achieve gender parity in politics and decision-making. In this context, the European project AR4ReClothing - "Stimulating gender-based innovative training methods to promote CLOTHING REcycling through Augmented Reality" — aims to involve textile professionals (manufacturers, designers, stylists, fashion designers, textile industry students, etc.) in promoting the environmental and social benefits of upcycling clothing through innovative training methods that better ensure environmental sustainability. This paper presents the content and principles of the innovative training methods developed by the project consortium, aimed at educating and training people on gender equality and raising awareness of the problems related to environmental protection.*

Keywords: *textile handbook, personalised, hands-on platform, mobile application, gender-sensitive training.*

1. INTRODUCTION

Gender inequalities and ecological activities are essential topics in the European Agenda and worldwide. According to the public data [1,2], women are involved in all types of professional activities and are concerned about environmental protection and using planet resources. Women work two-thirds as many hours as men and depend more on plants for their needs [3,5]. Despite all the attempts to provide eco-friendly activities, more must be done to ensure gender equality [6,7]. The European initiatives attempt to promote environmental sustainability, but there is no specific campaign to encourage women's participation in upcycling practices, despite garment upcycling being the newest eco-friendly direction for garment and fashion industry [1,3].

All members of our society need to know what measures are appropriate to preserve our natural resources and, above all, to educate children, the younger generation, colleagues, employees and family members to treat the environment responsibly. In the fashion and garment industry, teachers, VET and textile professionals (manufacturers, designers, dyers, etc.) need an open dialogue to support gender-responsive education that addresses environmental issues through clothing upcycling activities. Recycling and waste management have taken on even greater importance, particularly in light of the current economic situation: the Ukrainian war and the coronavirus outbreak [1,8]. Promoting a gender-responsive environmental strategy is crucial as women's roles in recycling and waste management are fast changing [7÷10].

Through creative training techniques that better ensure environmental sustainability by utilising women's varied but significant role in ecological activities, the AR4ReClothing Erasmus + project seeks to increase awareness of the environmental and social benefits of upcycling clothing while promoting environmental sustainability through gender equality. The project consortium has developed training content based on their experience in developing, promoting, testing and disseminating innovative training methods, tools and products: an inclusive handbook for textile professionals (a guide for textile experts on topics such as raising awareness of the current situation in EU countries regarding environmental initiatives and gender equity for sustainability; providing ground rules and successful practises for upcycling clothes through gender-sensitive training methods), a personalised, hands-on platform (an interactive online course that will serve as a comprehensive training programme), a gender-sensitive training method and an accreditation and certification programme for practitioners are the project outputs.

This paper points out the methodological research framework, the skills, knowledge and competencies that can be acquired after studying the contents of all training materials and that will help the trainee to engage/integrate in today's textile industry requirements that focus on sustainability and gender equity.

2. BRIEF PRESENTATION OF THE INNOVATIVE TRAINING METHODS

Upcycling clothing is a developing trend in green fashion; despite the EU's environmental commitment, there is no real attempt to get women interested in upcycling practices. Textile experts and VET teachers must have an open discussion on gender-based training in order to address environmental problems. Upcycling garments is a creative endeavour that complies with EU resource efficiency targets.

The consortium of the AR4ReClothing project has developed the content of all needed training materials suitable to be used and applied for any person's education regarding gender problems and environmental protection [1,11,12].

2.1. An inclusive handbook for textile professionals

For textile experts, the handbook will serve as a practical guide covering the following subjects: raising awareness of the current status of environmental initiatives and gender justice for sustainability within EU countries; offering guidelines and best practices for clothing upcycling through gender-sensitive training methods.

2.1.1. Research methodology

In the beginning, the members of the project consortium have carried ou research in their countries to describe the actual situation and identify the needs. The findings demonstrate that there is no proof that policies and training methods that are based on gender exist to support environmental sustainability, particularly with regard to upcycling of garments. According to the data gathered, there is not enough emphasis placed on promoting gender equity and environmental sustainability, which causes companies to lag behind in actively engaging in environmental initiatives that take diverse gender roles into account. Therefore, the current research will fill the gap that appears to exist, which is relevant among all EU countries, as revealed in the Institute of European Environmental Policy.

The partners have conducted national desk research and a national needs analysis, defined the training learning objectives (knowledge and competencies framework), and elaborated the training guide structure and methodology. Figure 1 presents the training process methodology according to the Standardised Methodological Framework [1].

- "Training requirements" → the consortium defined the purpose of training and audience profile.
- "Training plan"→ the partners have defined the training sessions (objectives, type of activities, agenda, infrastructure requirements), have elaborated the content of the training materials, have defined the time schedule, elaborated the evaluation forms, and have defined the participants' selection criteria.
- "Training execution" →the process will be conducted according to the training plan; the trainees will be attracted to participate actively; ask questions, and express personal ideas regarding the topics they would like to be trained; a hands-on training or tests to the reference environment may be performed and each trainee will execute the pre-defined scenarios in the simulator.
- "Training evaluation"→after training, each trainee will be asked to evaluate the course regarding the level of information they received and skills obtained through the courses. In addition, an expert will evaluate the simulator/reference environment test results. The answers provided in the evaluation forms, along with the evaluation results of simulator/reference environment tests, may determine further training requirements that will have to be satisfied by organising additional courses or hand-on training sessions.

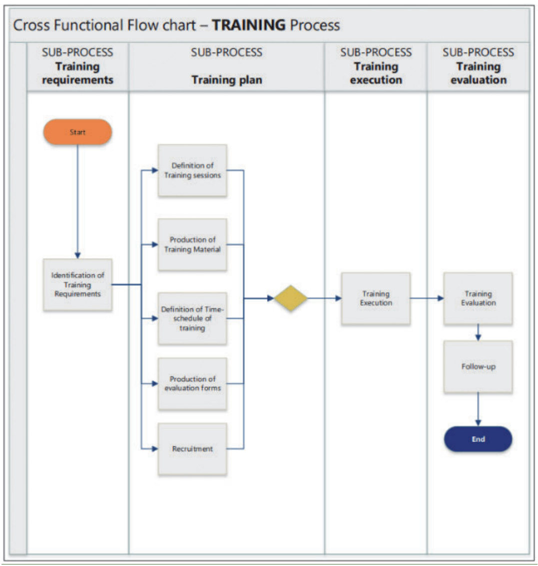

Figure 1. Generic methodological framework – training process [1]

The content of the modules was developed in English and then translated into all the partners' national languages.

2.1.2. The main features of the module content

Figure 2. Ecofeminism [1]

Module 1: *The role of gender equality in environmental sustainability and gender-based training methods.* The module presents the role of women in environmental sustainability, environmental awareness and relation with new training methods based on gender and environmental sensitivity.

After studying the contents, the participant will acquire the following knowledge, skills and competencies (see Table 1) [1]:

Table 1

Knowledge, Skill and Competencies

Knowledge	Skills	Competencies
Identify the current issues between environmentalism, gender equality, and gender awareness through education.	Explain the difference between ecology and environmentalism, between recycling and upcycling, and between feminism and ecofeminism.	Providing solutions to climate change from an equitable and sustainable perspective
Name great women activists and environmentalists	Analysing the problem of climate change and judging the veracity of current facts and news	To produce and create an environment that is sensitive to environmental protection
Define the concepts of environmentalism, ecofeminism, climate change, gender equality, recycling and sustainable and inclusive growth.	Distinguishing between coeducation and co-education	To raise awareness of the importance of equality and sustainability

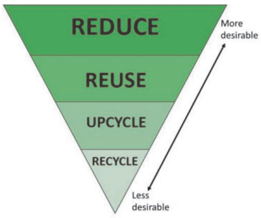

Figure 3. Textile waste management hierarchy [1]

Module 2: *Sustainable Practices in Clothing Manufacturing.* This module presents concepts and solutions that can be implemented in the garment industry to transform it into a sustainable industry.

After studying the contents, the participant will acquire the following knowledge, skills and competencies (see Table 2) [1]:

Table 2

Knowledge, Skill and Competencies

Knowledge	Skills	Competencies
Identify the category of textile waste.	Distinguish the categories of textile waste and their source	Raise awareness to reduce the amount of waste
Describe the importance of textile waste in transforming the clothing industry into a sustainable industry.	Explain the problems caused by the different types of waste and their minimisation techniques	Provide solutions for the reuse of textile waste in different production processes
Formulate recycling and manufacturing habits for products made of reusable materials.	Analyse the problems caused by textile waste and consumer behaviour for the environment.	Provide solutions for upcycling and recycling of worn garments and educate customers to act sustainably.

Figure 4. Clothing from fabric leftovers and scraps. Designers: Krista Volodina and Laimdota Vilcena (RTU University) [1]

Module 3: *Clothing up cycling as a green practice.* This module presents the basic principles of clothing "upcycling" and mentions other ways that could minimise textile waste - reducing, reusing and recycling.

After studying the contents, the participant will acquire the following knowledge, skills and competencies (see Table 3) [1]:

Table 3

Knowledge, Skill and Competencies

Knowledge	Skills	Competencies
Know the basics of clothing upcycling.	Describe sustainably clothing design and upcycling.	Raise awareness for sustainable clothing design and upcycling
Recognise sources of textiles used in the upcycling process.	Describe clothing design sustainably and upcycling.	Select and provide solutions for the clothes, fabrics/materials upcycling, and reuse
Identify types of clothing upcycling.	Select the most appropriate upcycling method for the clothing design.	Provide solutions for clothing upcycling.
Identify types of clothing upcycling.	Choose the most appropriate promotion and scaling-up strategy.	Provide solutions for promotion and scaling up strategy.

Figure 4. Clothing industry [1]

Module 4: *Soft Skills for clothing manufacturers.* This module presents the significance of soft skills in the garment industry.

After studying the contents, the participant will acquire the following knowledge, skills and competencies (see Table 4) [1]:

Table 4

Knowledge, Skill and Competencies

Knowledge	Skills	Competencies
Learn all about skills for Business.	Distinguish between soft and hard skills.	Develop a proper skill set required for a job.
Learn about the clothing industry today.	Evaluate your skillset.	
Learn about woman's position in the clothing industry.	Find ways to develop new skills or strengthen existing ones.	

Figure 5. Inclusivity [1]

Module 5: *Gender-equal digital competencies for clothing upcycling.* This content is about raising awareness of gender gaps in digital competencies and promoting the equal use of technological advancements for the sake of the clothing upcycling industry.

After studying the contents, the participant will acquire the following knowledge, skills and competencies (see table 5) [1]:

Table 5

Knowledge, Skill and Competencies

Knowledge	Skills	Competencies
Identify gender barriers.	Critical thinking.	Problem solving.
Develop an action plan.	Pragmatic thinking.	Productive choices.
Basic digital tools for clothing Upcycling.	Identify tools to meet your own needs.	Implement an action plan.

2.2. Personalised hands-on platform

The result is an interactive online course that will serve as a complete training package. In particular, it contains motivational workflows to enhance learners' performance in improving their training skills, thereby enabling them to pass knowledge to others in an appropriate manner (see Figure 6).

After accessing the platform, the user can browse its content and choose the desired topic to study. They can open the material (the booklet), take the quiz (knowledge assessment) and play the minigame.

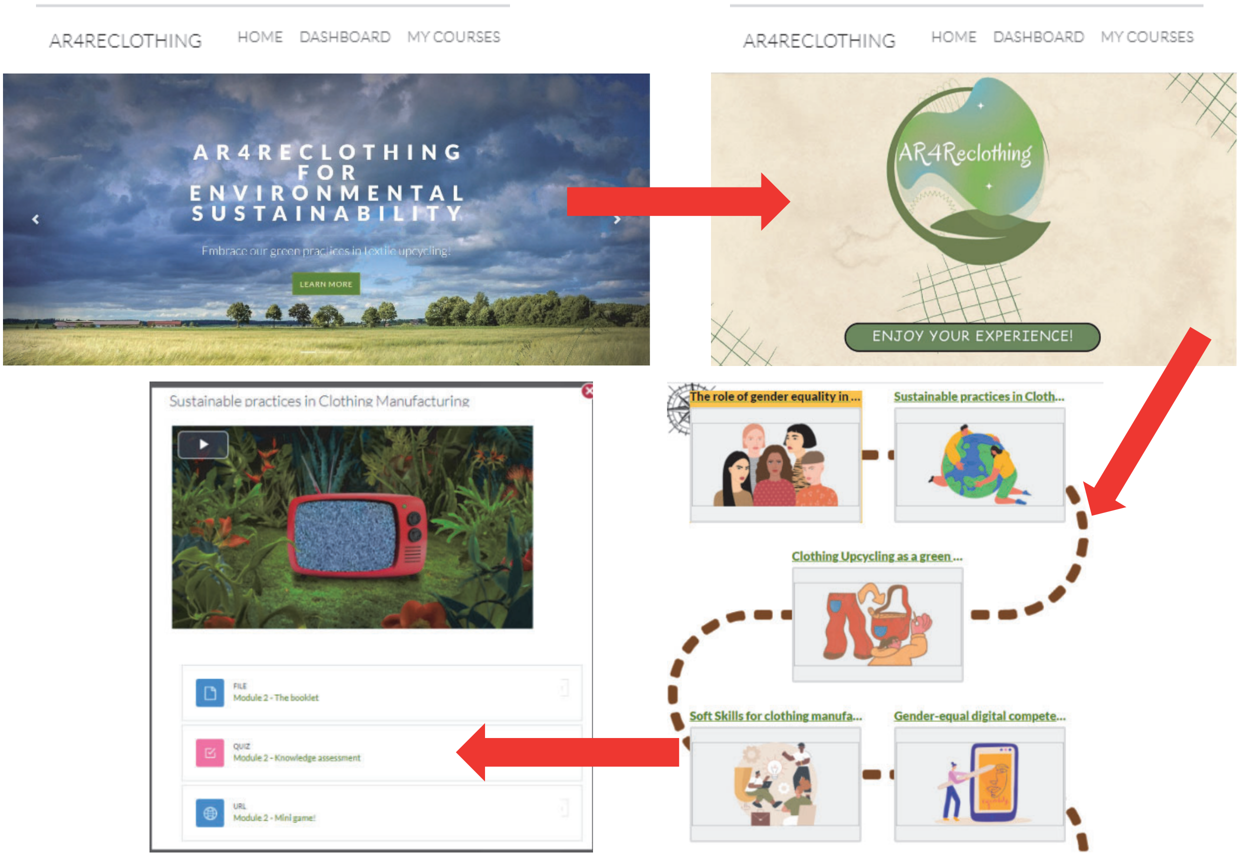

Figure 6. AR4ReClothing personalised hands-on platform [1]

The platform gives users access to various environments where they can find upcycling activities for clothes. The spots can contain multimedia content that provides helpful information and reporting tools that show how many project spots have been visited. Depending on this number, a points system will serve as a motivating workflow. Each time users visit a project spot, they will be confronted with different information, which will help them consolidate their knowledge and improve their skills.

2.3. A mobile application

The AR4ReClothing mobile app aims to enable participants to raise awareness regarding the connections between environmental sustainability, waste management and gender equality. To facilitate the investigation, processing and publication of environmental information, an open-source platform is used as a basis. The AR4ReClothing Mobile App is intended to serve as an eco-app that uses technology for the environment, as it is based on open-source platforms that are constantly developed and enhanced by programmers around the world, ensuring the highest level of sustainability (see Figure 7).

With this app, the trainee will be able to:

- ✓ Easily access course content→ browse the content of the courses, even when offline;
- ✓ Connect with course participants →quickly find and contact other people in the courses;
- ✓ Keep up to date→receive instant notifications of messages and other events, such as assignment submissions;
- ✓ Submit assignments →Upload images, audio, videos and other files from the personal mobile device;
- ✓ Track personal progress →View the grades, check completion progress in courses and browse personal learning plans;
- ✓ Complete activities anywhere, anytime→attempt quizzes, post in forums, play SCORM packages, edit wiki pages and more - on and offline.

Figure 7. AR4ReClothing mobile application [1]

The present application uses marker-based AR software to help users navigate through the content. This requires real objects to be pre-determined along with the digital information they will represent so that the camera can identify them. In this project, the tangible object for the game will be a printed A5-sized handbook (cookbook) that reveals segments (small portions) containing information about the educational modules of the project. The content will be derived from the 'ReClothing Training Guide'.

2.4. Practitioners accreditation & certification

This project outcome aims to facilitate the valorisation of project outcomes according to the EQF and related instruments to improve their efficiency and attractivity.

The AR4ReClothing BADGES are a certification specific to the EU labour market, as they are issued according to a standardised accreditation system recognised by the EU. Therefore, professionals working in the garment industry have access to a legitimate EU certification that recognises their recently acquired knowledge and skills that match the labour market requirements. This aspect alone makes them attractive to employers and job seekers. In addition, the fact that the official exams are conducted online gives candidates access to a fair and open validation and qualification system.

One of the greatest advantages of this certification is that organisations, IT companies, environmental clusters, industry experts and certification bodies are pooling their resources to create a solid platform for training and validating competencies that will serve to engage industry experts in ongoing training opportunities:

-The certification system will incorporate the requirements of various national qualifications frameworks. The current outcome will enable the restructuring of training provision by sharing best practices.

-This model is subject to the rules and procedures of the national accreditation bodies of the European Union (European Cooperation for Accreditation). The 'AR4ReClothing BADGES' are certifications specific to the EU labour market as they are produced according to a standardised accreditation system recognised by the EU.

–Industry professionals can obtain a legitimate EU-recognized certification for their recently developed expertise and competencies that meet the labour market requirements. This aspect alone will make them attractive in the real world of jobs and the labour market. In addition, the fact that the official exams are conducted online gives candidates access to a fair and open validation and qualification system.

-The project consortium will use the EQAVET [11] methodology in conjunction with a qualification system to apply the framework in a VET initiative. This full cycle of preparation and certification means that all EU Member States wishing to replicate the process will be able to adopt high-quality qualification requirements.

3. CONCLUSIONS

The AR4ReClothing project aims to provide a solid and yet innovative training methodology that can be used by VET trainers who are oriented towards societal needs, in particular, current environmental practices and gender-responsive approaches, as well as future needs in this field, in order to promote the growth of the EU circular economy. In particular, a gender-sensitive approach is offered as part of the training guide, linked to user engagement technologies and networking and internalisation activities facilitated by the project club, which will serve as a central communication point for practitioners.

Compared to other European project initiatives (for example: Design4Circle, ECO-TEX, OptimTex, EDRESS, Digital Fashion, TexMatrix, Skills 4 Smart TCLF Industries 2030, E&E Fashion, Fit2Com, Advan2Tex, etc.) that focused on training textile industry employees/experts on issues related to digitalisation, circular economy and sustainability principles, the AR4ReClothing project aims to raise awareness among textile professionals (manufacturers, converters, designers, stylists, fashion designers, textile industry students, etc.) about the environmental and social benefits of upcycling clothing through innovative training methods that better ensure environmental sustainability utilising the different roles of women in environmentally friendly activities. The project covers the need of VET trainers and textile professionals (manufacturers, designers, etc.) to engage in an open dialogue in order to support gender-based training towards buckling down environmental challenges through clothing upcycling activities and constitutes a brand new initiative in alignment with EU goals for resource efficiency (Europe 2020 Strategy) that promotes the women's role in the recycling process as well as waste management [12].

Acknowledgements

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USE OF MICROLEARNING AND MICROCREDENTIALS IN TEXTILE ENGINEERING EDUCATION

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Abstract. *Learning does not stop at graduation, it continues throughout life. For this reason, one of the continuous learning methods is microlearning. It consists of organizing course content into teaching units that can be easily remembered. Microlearning has many benefits: it improves recall and knowledge retention, it can be highly customizable and adaptable, and it is easily accessible. Small individual lessons can be created that typically contain a measurable learning outcome that is skill-based, a form of digital instruction, and allow for rapid content assessment. Microlearning is a form of competency-based education (CBE). CBE is designed so that individual learners can personalize their learning by choosing the skills they need to improve and upgrade or qualify for the careers they want, whereas in traditional education students can focus on those skills that will benefit them in their careers. CBE is a term that encompasses needs-based and objective-based approaches to teaching and learning, it offers open digital micro-credentials (called open badges). Other users prefer to use the term micro-credential to represent greater learning content than the open badge. Microcredits are credentials, earned through microlearning. These credits allow learners to demonstrate to current or future employers that they have or have improved the required skills. This is useful in a career. Academic institutions typically create microlearning programs to obtain micro-credentials. The article outlines how a Moodle learning management system (LMS) can be utilized to create content that follows microlearning principles and issue microcredits after completing a course.*

Keywords: *microlearning, microcredentials, Moodle, competency, learning.*

1. INTRODUCTION

Lately, the world is undergoing rapid changes that affect work and private life equally, so people need to adapt quickly to these continuous changes in the work environment. These changes happen at smaller and smaller intervals that require learning new skills as quickly as possible. The ability to learn and the speed of learning thus become a fundamental factor for the quality of individual life. Advanced education and training will occupy a rather important part of our lives that should not be underestimated.

The prevailing model of education is the one that was popular during most of the 19th and 20th centuries and can be called the "industrial model of education" [1]. This model focused on preparing professionals for a job or career and only then requiring them to perform activities for which they had relevant skills.

The necessary skills are acquired in the traditional way but also with the help of modern e-learning systems. E-learning is based on using electronic media for various learning purposes, ranging from additional functions in conventional classrooms to the complete replacement of face-to-face meetings by online meetings [2]. The learning management systems used today (different e-learning platforms, MOOCs, etc.) have the advantage of allowing learners to access the necessary information whenever and wherever they are, provided there is an Internet connection. Accessing these LMSs is advantageous because they are accessible to students.

In today's information age, dominated by relatively easy access to technology, devices and online content, there is a need for a new model of professional learning that emphasizes timely training, provides focused information, flexible and accessible models of learning adapted to the objectives of professionals but also students. Microlearning is an innovation developed to meet the educational needs of the 21st century, providing quality professional learning in formats that can more easily support the continuous development of students' skills or for employees the development of their own careers and implicitly of organizations.

Microlearning is a form of e-learning where information is delivered in small chunks, focused on providing skill-based and timely knowledge [3], as opposed to traditional training, which may require long sessions in advance or interruption of on-site performance for work. The average adult studies up to 20 minutes per week for work [4], and interruptions can cause work or learning stress and extra effort [5]. 96% of people, when they need it, look for information online [6], and microlearning is suitable for modern workplaces. as well as traditional education. Individual lessons contain a single measurable learning outcome that is skill-based, and are a form of digital instruction allowing for rapid assessment.

To assess knowledge through microlearning, grades are awarded, and a recognized certificate is used to attestation these skills. Micro-credentials are certificates that are awarded for specific skills. Recognition and communication of achievement in a variety of learning domains, covering both formal and informal learning contexts, has been achieved through the development of micro-credentials and digital badges in the (primarily) online domain. In the context of small learning packages, the term "digital badge" is present in the educational lexicon, and even some higher education providers have chosen to label their online short courses as "digital badges". Other higher education institutions offer short online courses called micro-credentials due to their interchangeability with the terms micro-credential and digital badge in the educational landscape. However, the European Commission (EC) in its 2020 report on micro-credentials [7] highlighted the lack of clarity regarding micro-credentials and digital badges and therefore sought to standardize these certificates. The Covid-19 pandemic has provided the impulse for the rapid implementation of micro-credentialing by governments in several jurisdictions [7], while international governmental organizations such as UNESCO and the OECD are increasingly focusing on micro-credentials [8], [9]. The European Commission has formed a consortium that has launched a common microcredit framework "…to create portable credentials for lifelong learners" [10]. It also emphasizes the need for a "common international approach where all aspects of a person's learning are electronically documented, authenticated and can be accessed anytime, anywhere, shared and modified by the owner or an authorized party", [9]. At this moment micro-credentials are developing more and more, there are policies at the national level to introduce them into the qualification frameworks, stimulated by international policies.

Even though several credential recommendations have been issued, there is currently no consensus on the term "micro-accreditation". Various terms are used that may be commonly associated with this term, which include (but are not limited to): digital badges, alternative credentials, digital credentials, nanodegrees, digital certificates, micro-masters, and online short courses. From an international perspective, the definition of micro-credentials is open to interpretation. As a result, the term "micro-credential" has been used to describe all types of the shorter forms of learning experience, regardless of type, mode and size [11].

Micro-learning and micro-credentials are competency-based education (CBE). The development of CBE began in the 1960s, although its predecessor - outcome-based learning, has been practiced for over a hundred years in adult education and professional development [11]. Compared to traditional teacher-led training, where learners have to distinguish skills, CBE begins with predetermined competencies from which training develops.

CBE must focus on individual student goals rather than universal goals [12]. The discrepancy between the skills taught in traditional higher education and the skills valued by employers is called the cultural gap between business students and academics [13]. This gap between the education received in academia and the knowledge not acquired in practice [14] includes differences in the perception of generic skills [15] and the lack of skills necessary for the employability of graduates [16]. CBE training allows individual learners to personalize their learning by choosing the skills they need, or enhance them to qualify for the careers they have or want [17], being achievable both academically and individually upon completion of studies. In a survey of 1,207 graduates of Western Governors University, an online university that offers competency-based programs, 78% reported that the skills they learned with the CBE approach were specific to their work—a number with 10% higher than traditional university graduates [18].

2. LEARNING MANAGEMENT SYSTEMS FOR MICROLEARNING AND MICROCREDENTIALS

E-learning is based on the use of electronic devices to pursue a multitude of learning goals, ranging from additional functions in conventional classrooms to completely replacing face-to-face meetings with online meetings [2]. E-learning is based on learning management systems that allow the development of materials and their structuring of learning. The LMSs in use today (different platforms, MOOCs, etc.) have the advantage of allowing learners to access the necessary information whenever and wherever they are, provided there is an Internet connection. The advantage of accessing these LMSs is that they are available to the student. An e-learning course can take a long time if the subject is very complex, the content can be too difficult to understand if it follows the requirements of a traditional course, and at the same time, it can discourage the student from taking it. For these reasons, it is necessary that the information is presented in a way that makes it accessible to students.

2.1. Microlearning and structure of Moodle course

By definition, microlearning describes: providing “bite-sized” information, but microlearning is more than small. Microlearning is not only compact in the structure of the information provided, but also focused, providing just the right amount of information needed to help a learner achieve a specific, actionable goal. This makes microlearning very useful both for training employees, but especially for students. They can extract from the course or laboratory material the essential elements for their preparation, without neglecting other elements. Microlearning is a useful and essential way to learn that involves short video demonstrations, packaged simulations, short 'gamified' activities, instructional animations, and rich visual aids.

This article presents two possibilities for adding specific activities so that the knowledge gained by students can be reinforced. The two methods can be applied by teachers, depending on their ability to use H5P tools or those offered by the Moodle platform. One such H5P activity is shown in Figure 1. It is a presentation of a course topic containing questions and media files embedded in the page. Creating such a presentation of a subject is similar to creating a typical presentation (PowerPoint, etc.), the content being structured on pages that include: text, images, video files and other elements such as dialogue cards, drag and drop, filling in spaces free, flashcards, interactive video, summary, image hot spots, etc.

Figure 1. Editing H5P content and structure of topic

This type of content can be edited very easily on the H5P.org page because it is: Open Source, Free to Use, HTML5, and Responsive. For teachers, the content developed on the site H5P course content can be integrated into the different platforms using a simple method. In the case of the Moodle platform, this content can be created thanks to the recently integrated plug-in.

Another type of activity that can utilize the principles of microlearning in student learning is the "Lesson" activity. A "Lesson" activity allows teachers to create "branching" exercises where students are presented with content about a topic and then directed to specific pages based on their responses. The content is structured on pages, which may contain: text, images or multimedia elements, followed by short questions that will allow you to navigate further through the Lesson, depending on the answer. If the answers don't match, you can return to the learning resource on the page before the question and take the test again. Completion of the Lesson is concluded when the student meets all the requirements of the Lesson, figure 2.

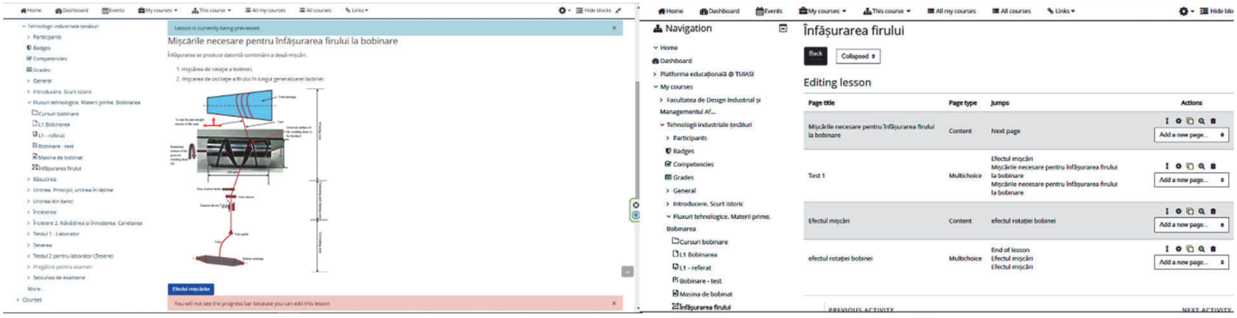

Figure 2. Structure of a Lesson in Moodle

Activities like this are necessary for accessing partial and final assessments. Assessments can evaluate both the steps taken to acquire knowledge about a specific subject and the course taken. Activities can be completed with a grade, but it doesn't have much meaning, so certificates or credentials are necessary for completion.

2.2. Microcredentials used in a Moodle course

CBE is an umbrella designation that embraces needs-based and goal-based approaches to teaching and learning, including open digital microcredentials (what many call open badges). While some prefer to use the term "*microcredential*" to represent a larger body of learning than the "*open badge*", the two terms are often used interchangeably [1]. The use of microcredit indicates educational progress within a course and has been adapted for students. By completing specific tasks, a student earns a badge. These badges were created and issued to validate a person's acquisition of a skill (competency), Figure 3.

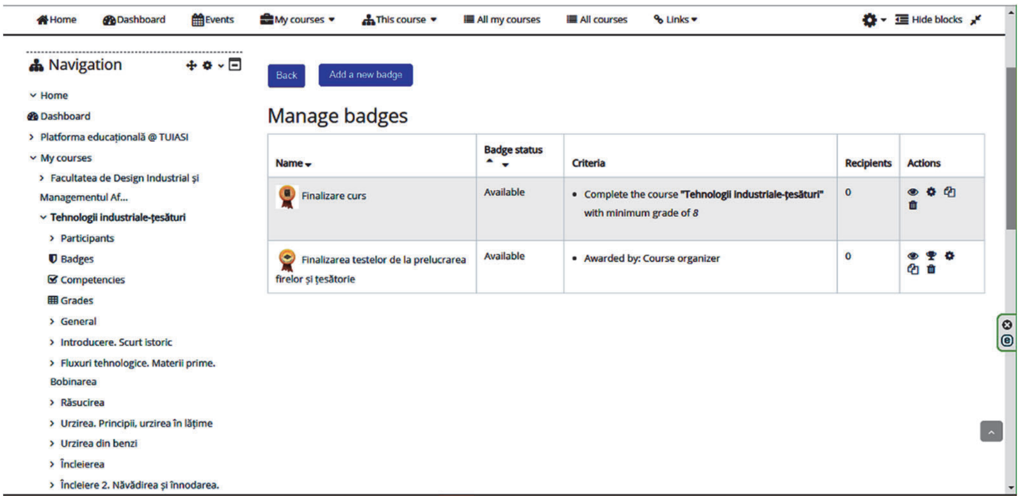

Figure 3. Badges awarded in Moodle for different activities (partial tests and course finalization)

In the case of the course in Figure 3, two badges are awarded - one for continuous activity during the semester and the other for passing the final exam. Continuous activity can be conditional on the completion of several activities (uploading reports, solving quizzes and passing partial examinations. The use of badges to stimulate learning through gamification was achieved by establishing a limit from which they are awarded, similar to game bonuses. The percentage of students who exceeded this limit in the interim quizzes increased from 30% in the first year to 57% after three years.

These badges are awarded for completing an activity, completing a course, or acquiring a skill. For this reason, they must have a series of recognition elements that attest to their validity for a future employer.

For this reason, the student, after receiving a badge, should save it in a digital backpack from which he can extract and present the badge he needs at a particular time.

For these reasons, in certain situations, micro-attestations can be granted in the form of certificates of completion of a course that include the acquired skills. This type of certificate will resemble a diploma, only it is awarded in digital format, certifies specific skills and is personalized, Figure 4.

Figure 4. Certify awarded in Moodle for course finalization

In the case of the certificate in Figure 4, sheets containing relevant information can be added - the field of graduation, the number of hours, the number of credits, the institution under whose authority that course was completed, etc. A certificate awarded upon completion of a microlearning course has several advantages over the badges. The *quality* of the graduate training can be checked due to the fact that that course is part of a program accredited by the relevant national authority, if the learning outcomes are in line with the requirements of the post for which they are applying. The certificate enjoys *recognition* - both academically and from the employer's point of view because it meets certain specific standards, *portability* - can be stored and distributed by the owner via e-wallet, *authenticity* - the identity of the certificate holder can be verified, to the issuer and the information contained therein.

Such certificates can also attest to the skills acquired, if the competency framework is entered on the platform by the LMS administrator.

3. CONCLUSIONS

In this article, the possibility of using Microlearning to create courses whose content allows the accumulation of skills is analysed. Microlearning consists of organizing the course into teach units that can be easily remembered and are carried out during periods of a maximum of 20 minutes. The benefits of such a system consist in improving knowledge retention, and quick recall, it can easily customized and adapted to the course content and learning requirements and is easily accessible.

Two types of activities (H5P and Lessons) were presents, which are find on a Moodle platform and which allow the provision of information according to the microlearning principle. Activities of this type provide measurable, digital results that based on a quick assessment of the skills acquired. This type of learning is the way that competency-based education is structured.

The evaluation of the skills acquired by the students is carry out in the same way as in a traditional course, and their recognition is certify with the help of badges or micro-certificates. In the case badges, the information about them must be stored in digital format in a backpack to which the recipient of badges makes access.

Micro-credentials are complex forms of certification because they contain much more information about the skills, who received the certificate, who was award the certification, and can be verify online. These microcredentials can be offer through courses belonging to a specific study program, and they must not exceed the framework imposed by the national agencies that aim to comply with the quality requirements.

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THE IMPORTANCE OF TEXTILE MATERIALS DATABASE

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Abstract. *The digitalization process is now very important for all the areas of our life and fashion industry is not an exception. The digitalization process is important for the sustenability issue, very actual issue in fashion field. In the frame of the project Erasmus+, Digital Fashion,2021-1-RO01-KA220-HED-000031150 an online digital fashion platform is developed. In order for this platform to be operational and to solve the needs of students, fashion designers and people from the clothing industry, it is important to have a good database, well-structured and full of data. One of the project results is focusing on building three knowledge libraries, one for textile materials, one for garment models and one for human bodies. The on-line platform developped in the project is based on these database, the data being provided by all the partners. In this paper it will be presented the need, the structure and the use of the textile material database. For the textile and garments models database, it will be presented the information provided by the team from the Faculty of Industrial Design and Business Management from Iași. These results can be used to develop a data base for technical textiles for protective garments.*

Keywords: *Erasmus project, library of knowledge, fabrics, raw materials*

1. INTRODUCTION

Digitalization and sustainability are two main factors of interest in EU for all the activity fields, but especially for textile and clothing industry. As textile and clothing industry is a manual labor industry and in our days in EU qualified human resources for these jobs are hard to find, digitalization in this sector may be the answer [1]. On the other hand, textile and clothing industry is considered to be one of the great polluters, this is the reason that supports the development of the digitalization process, leading to 4.0. industry.

Good software application are based on comprehensive and well structured database. The development of textile database is usefull for all the links of the value chain of a garment manufacturing company, from raw materials purchase, to product design and development, ending with the distribution area, especially when the e-commerce is involved. Textile materials digitization and the development of the library of knowledge, textile database, digital library, digital gallery have the following advantages:

- lower impact of the textile materials over the environment;
- it is easy to store and update digital data;
- can be used by persons with different fields of interest, students, designers, people working in textile and garment industry, persons developing e-games;
- financial efficiency;
- elimination of stocks and warehouses;
- transparency in the fashion industry and reducing the need for physical samples.

In this context, the development of a DigitalFashion on-line platform, based on three database, is the main subject of the Erasmus+ project *Digital Fashion- Collaborative Online International Learning in Digital*

Fashion [2]. The project is developed in the frame of European Commission's ERASMUS+, Strategic Partnerships for Higher Education and has a duration of 36 month, ending at the end of January 2023.

There are five partners involved in the project: "Gheorghe Asachi" Technical University of Iasi – Romania (TUIasi), National Higher School of Arts and Textile Industries from France (ENSAIT), HOGENT University of Applied Sciences and Arts from Belgium, University of Maribor from Slovenia and Textile and Clothing Technological Center from Portugal (CITEVE) and the project coordinator is National Research and Development Institute for Textile and Leather from Romania (INCDTP).

The following are the outcomes of the DigitalFashion project:

- A fresh approach to an international framework for collaborative online learning in the digital fashion industry;
- Creation of three databases with models, patterns, and textile materials for clothing;
- An online digital fashion platform for designers, students, and fashion industry professionals;
- An online curriculum built around the new digital fashion collaborative online module, which will feature updated methods for fashion co-design training and assessment;
- Dissemination of the work done in the project.

The aim of the paper is to present the results obtained in the project regarding the data base developed to support the on-line platform and how these results can be used to develop a data base for technical textiles for protective garments.

2. METHODOLOGY

The first issue consists in establishing the aim, the structure and who will benefit from the textile and garments database. According with the recipients of the library of knowledge and its purpose, the necessary data and the way in which the image of the textile material will be insert will be established. It is determined also the size of the library. Finally, the necessary data of the items will be insert in the library.

In the DigitalFashion project, according with the experience of the partners in the field of digitalization of fashion industry and education, it was established first a textile database for four types of garments, namely blouse and skirt for women, shirt and trousers for men. For these garments types two or three models for each type were proposed, as starting point of the database.

Each partner made a selection of fabrics suited for the proposed models [3]. For the validation of the three database, physical prototypes for two models and two fabrics from the digital library were realized [4, 5]. The fabrics from the database were assimilated with fabrics from Lectra database and the virtual garments were compared with the physical once.

2.1. Method for digital image of the fabrics

The image of the fabric can be obtained in different ways, by scanning with special scanners, by photographing, by creation of digital images or by rending etc.

The most common and easy way of textile materials digitalization is using a smartphone. The producers offer specialized apps with the possibility of image editing so that the final result is closer to the real image. Using this method a good image can be obtained.

For a better image of the textile materials there are on the market specialized scanners. The TAC7 scanner effectively measures and stores colour, size, texture, gloss, transparency and other appearance characteristics of even the most complex materials [6]. x-Tex scanner - provides the ability to obtain clear digital images of physical samples. The 8-light set provides the guarantee of capturing the surface accuracy of the scanned material [7]. The Vizoo A2 allows range of capture and scans from 350 to 750 dpi (dots per inch - a measure of the resolution of a printed or digitally scanned document), while the A4 scanner offers 600dpi to 2000 dpi [8]. Especially for textile materials can be used Nuno 3D scanner - an advantage that has the ability to render the layout of the fabric for an accurate 3D version [6]. Several businesses, including the Pantone, X-Rite, Material Exchange, Vizoo and CLO are engaged in the process of creating realistic virtual textile materials [9, 10]. Browzwear Fabric Analyzer facilitates the actual process of making tangible samples, even before they are manufactured, for fashion designers and merchants.

The rendering process means editing digital information including reflected and absorbed light, textures and volumes. In the end, it is possible to transform these data into a 3D model, into final images that are visible on the monitor or on paper. All of these components are introduced and processed in a graphical 3D modelling environment. The best designers in a variety of fields, including interior design, architecture, and textiles, frequently employ rendering (example in figure 1).

Figure 1. Rendering used by fashion designers (https://jeenlun.wordpress.com/gallery/232-2/ accessed on 04/09/2021)

For the database developed in the project the image of the fabrics will be obtained by photography.

3. RESULTS AND DISCUSSION

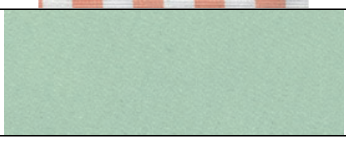
3.1. Textile materials database

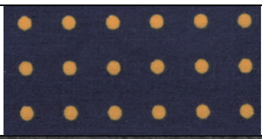
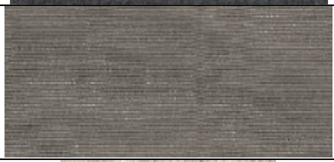
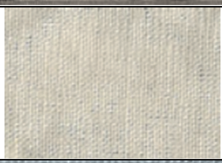
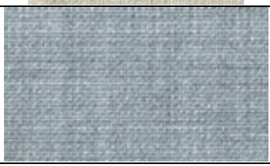
The database created by TUIasi consists in eight fabric types, with different characteristics (table 1). The destination of the textile material was appreciated by the TUIasi team, based on their vast experience in the field. The colour was appreciated according to Pantone code, the technical parameters, density, weight, thickness, fibrous composition were provided by the supplier or determined in the laboratories of Industrial Design and Bussiness Management Faculty from Iași. The final two parameters, namely see through and feel/touch were subjectively evaluated by the faculty specialized staff. All the fabrics are weaves, canvas type, best suited for the proposed garments models. The database contains the most relevant information needed for virtual garment 3D.

It can be appreciated that the textile materials selected in the database are very different, so that a designer has many options.

Table 1

Fabric database

Item	Image	Destination	Color	Composition	Density (warp/ weft/cm)	Weight (g/m^2)	Thickness (mm)	See through	Feel/ Touch
1.		Shirt, blouse	Pink 2153	75% viscose, 25% cotton	20/33	75±3	0.23±0.02	NO	smooth
2		Shirt, blouse	Orange/white plaid 0904/0010	60% viscose, 37% cotton, 3% elastane	29/52	170±3	0.33±0.02	NO	Slightly rough
3		Blouse, dress	Light green 4250	100% PES	35/66	110±3	0.30±0.02	YES	Soft, little rough

Item	Image	Destination	Color	Composition	Density (warp/ weft/cm)	Weight (g/m^2)	Thickness (mm)	See through	Feel/ Touch
4		Blouse, dress, skirt	Navy blue with yellow printing	100% viscose	43/67	80±2	0.27	NO	Soft
5		Skirt, trousers, jackets	Dark grey 4174	98% wool 2%elastan	23/31	210±5	0.46	NO	Soft
6		Skirt, trousers, jackets	Beige sand 0874	60% cotton, 40% PES	28/45	150±5	0.35±0.05	NO	Soft, little rough
7		Skirt, jacket, trouser	Light Beige 0970	100% viscose	24/27	150	0.34±0.05	NO	Little rough
8		Skirt, jacket, trouser	Light gray 3770	97%viscose, 3%elastan	39/59	370±7	0.93±0.05	No	Smooth

After analysing the models from the garments database (table 2) another data was considered necessary, for a comprehensive characterization of the fabric. This is why another technical parameter, drape, was in the end added. The textile database was integrated in the Digital fashion on-line platform and used for garments design (figure 2).

Figure 2. Fabric database in DigitalFashion on-line platform

3.2. Garments models database

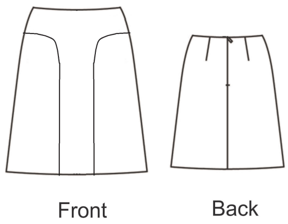
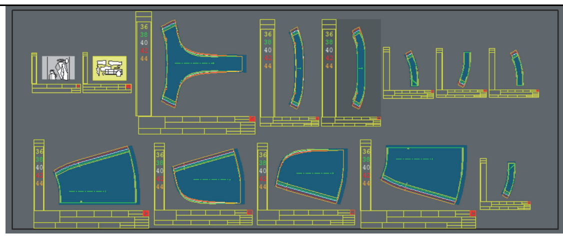
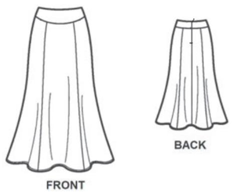
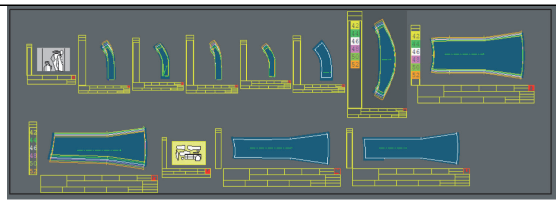
The garments models database consists in two different models for each type of garment, namely skirt, blouse, shirt and trousers. In table 2 it is presented a small part of the database proposed by the TUIasi partner.

There are presented the necessary information for a comprehensive characterization of the model, namely technical sketch, front and back, short description of the model, digital patterns with grading.

The models were used for designing a virtual garment and then, comparing the virtual result with the real one, it will be evaluate if the information about the fabric from the database is sufficient or not.

Table 2

Garments models database - sequence

Model	Technical Sketch	Description	Digital patterns with grading
1		Skirt with central front panel, slightly flared, two darts and central seam on the back. No visible waist belt, zipper on middle back	
2		Flared skirt with wide waist belt, three panels on the front and four panels on the back, zipper on middle back	

4. CONCLUSIONS

Fabric database is a very important tool for the digitalization of garment design. The main features for a suitable library of knowledge were respected at the filling out of the textile and garment database. More fabrics and garment may be added to the database when it is necessary.

Using the same principles, suitable database can be built for other types of garments or raw materials. The database for protective equipment must be built on starting with the specific of the equipment, then decide on the image type and necessary parameters.

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TRAINING GUIDE FOR DESIGNING 3D KNITWEAR FOR TECHNICAL PRODUCTS

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Abstract. *The usefulness of producing three-dimensional (3D) shapes using the weft-knitting technology has been demonstrated in recent years in the apparel industry, but mostly in the technical field. Flatbed automatic weft knitting machines are capable of producing sustainable shapes with complex designs that offer benefits such as waste minimization and optimization of yarn consumption before the final product manufacturing. Computer Aided Design (CAD) system software plays an important role in the development of a 3D knit fabric. It provides the digital interface necessary to develop the program containing instructions for the knitting parameters used by the knitting machine having its specific drawing functions and options. Designing a three-dimensional knitted shape on a CAD system requires a mixture of knowledge between two components: pattern programming and shape architecture. The relationship between shape and surface requires a deep understanding. This approach must be made with consideration of the programmer's skills, design parameters, and technical constraints. The geometry of a 3D model must first be translated into a suitable two-dimensional (2D) pattern that represents the specific design elements like a diagram. The second step is to build the knitted areas that will result in a proper knitted and optimised model. These areas can be either made directly on the shape or just imported from a data base previously created. The last step is to determine the technical parameters suitable for the knitting process. The paper presents the methodology developed by the authors as a training tool for designing 3D knitted shapes for technical end-uses. Considering the high complexity of programming stage with special software, such as M1plus® by Stoll by KARL MAYER, the purpose of elaborating this conceptual approach is to make this activity easier to understand and more attractive from a creative point of view.*

Keywords: *3D knitted shapes, CAD system, pattern programming, shape architecture, educational tool, technical applications.*

1. INTRODUCTION

Advances in manufacturing technology have evolved to enable the production of fast, low-cost, and accessible products that must meet custom product requirements. Production methods that offer speed, flexibility, and no waste are the most anticipated requirements [1]. The knitting industry has come very close to these development trends through the constant modernization of knitting machines and knitting design software. Electronic flatbed weft knitting machines are capable of producing sustainable shapes with complex designs that offer benefits such as waste minimization and optimization of yarn consumption before the final product is produced [2].

The possibility of producing 3D shaped goods has been extensively demonstrated by weft knitting technology not only at textile and apparel exhibitions [3], but also by many research works [4], [5], [6]. Its application areas are developing over time from the fashion industry to the production of garments to goods for technical applications [7], which account for the largest share of 80% in the world knitted fabric market in 2018 [8].

Knitting machine shaping technology requires a good knowledge of the two main components: pattern programming and shape architecture. Computer Aided Design (CAD) system software plays an important role in the development of a 3D knitted fabric. It provides the digital interface required to develop the program that contains the instructions for the knitting parameters used by the knitting machine with its specific drawing functions and options. The complexity of the software makes it difficult to manage the programming tools, which are mainly reserved for programmers and less for designers due to their technical know-how [9]. In order to achieve a better communication between artistic creation and digital creation, it is essential for both parties to have a better understanding of some principles and techniques that govern the production of knitwear [10].

This paper presents the methodology developed as a training tool to design 3D knitted shapes for engineering end-uses. The learning outcome is intended to help participants better understand technological concepts and translate a conceptual design into a feasible knitted piece. The concept material includes knitted structures, modelling techniques for shapes, and the principle of making knitwear with 3D shapes to make programming in knitting courses more effective.

2. BASIC KNOWLEDGE FOR SHAPING TECHNIQUE

2.1. Knitted fabrics with shaped design

Shape, as defined by the Cambridge Dictionary, is the particular form or geometrical shape of something. Knitted fabrics have the ability to take on complex shapes, either through the application of tensile forces (which create the desired shape due to the elastic behaviour of the yarn) [11], [12] or through the process of knitting [4], [5], [13]. Each of these shaping processes has its advantages and limitations. The choice of the right process depends on the end use of the final product and its requirements.

Weft knitting technology have the possibility of creating shapes by increasing or decreasing the number of needles in work. This can be done using narrowing, widening and bind-off techniques but also with the method or partial row knitting [13].

Strength or stability of a fabric can be better matched by combining yarn, structure, and stitch density parameters in knitting. Shapes can be created by combining stitch structures. 3D shapes can be achieved by combining rib structures and single jersey structures in an alternative sequence. The effect is created by the aesthetics of each knitted structure in a relaxed, static state, as the rib structure shrinks after knitting and the single jersey remains flat, almost in the same shape as it is produced during knitting. If, in addition, the stitch density is varied, various changes in shape can be achieved.

The strength and stability of the fabric can be achieved also by varying the orientation of the yarns in the structures, which can be added to the knitted structures. Either it is tucked and floated on one side, tucked to connect two individual layers, inserted on weft [14] or wrap direction [15], they aim to raise these properties of the knitted fabric.

The type of machine is also a determining factor in the production of a knitted design. The number of needle beds, the width of the needle bed, the gauge of the machine, the type of yarn feed, the number of systems, the type of take-down mechanism, and all other technical factors that affect knitting are critical to the manufacturing process.

CAD system software have the right tools for designing knitted fabrics and especially in the process of developing 3D shapes. The process of using digital knitting to create 3D shapes requires knowledge of the construction of shape patterns and the specifics of the knitting process (stitch structures, knitting techniques, setting knitting machine parameters, and knowledge of digital design programming).

The examples presented in this paper were elaborated on the Stoll M1plus® CAD system. Since they have a didactic purpose, their dimensions are not scaled 1:1.

2.2. Guidelines for shaping knitting

Developing a three-dimensional knitting shape is a complex process and requires a team effort between designer and technician/programmer. To achieve a good result, some preparatory steps must be followed. They form a bridge that allows better communication between the designer, who creates the product, and the programmer, who creates the digital knitting program required for the knitting machine. To ensure a smooth workflow, the following steps can be followed.

1. Creating a sketch of the product

For better understanding, a sketch of the product must be made, accompanied by a description (Figure 1). This information may include a description of the individual parts, the colour palette and the type of yarn to be used.

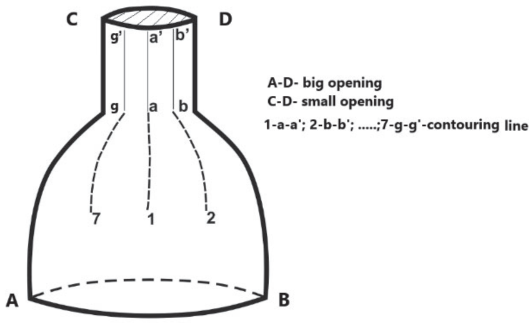
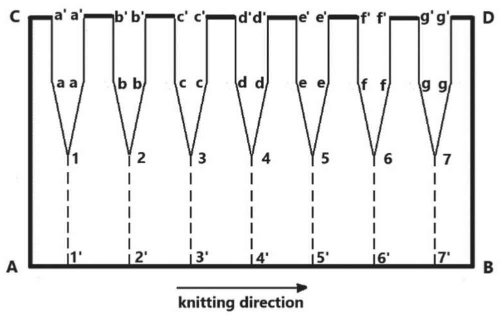


Figure 1. Knitted shape [16]

2. Shape dimensional specifications

A schematic drawing in the form of a suitable two-dimensional (2D) pattern corresponding to the geometry of the 3D shape with the overall dimensions of the components (Figure 2) must be submitted. This step is necessary to select the correct knitting machine taking into account the needle bed dimensions of the machine.



Section	Dimensions [cm]
A-B	30
A-C; D-B	20
1-1'; 2-2'; 3-3'; 4-4'; 5-5'; 6-6'; 7-7'	8
1-a; 2-b; 3-c; 4-d; 5-e; 6-f; 7-g	6
a-a'; b-b'; c-c'; d-d'; e-e'; f-f'; g-g'	6
C-a'; a'-b'; b'-c'; d'-e'; f'-g'; g'-D	1

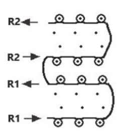
Figure 2. 2D flat shape of the tube and the requested dimensions [16]

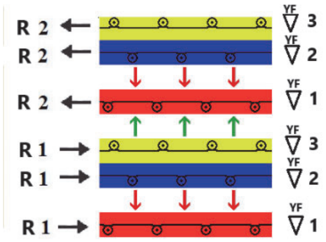
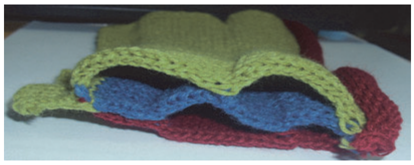
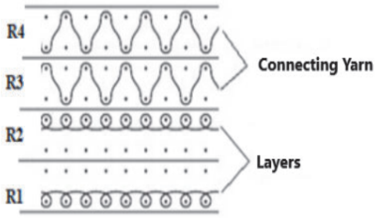
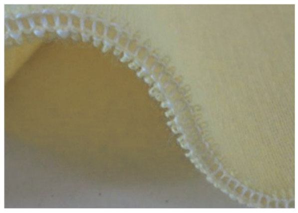
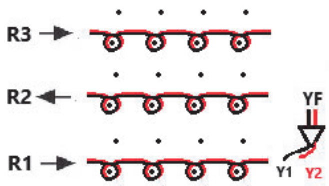
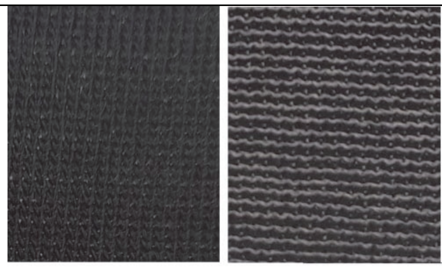
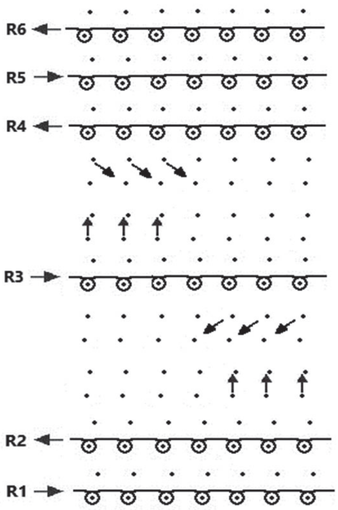
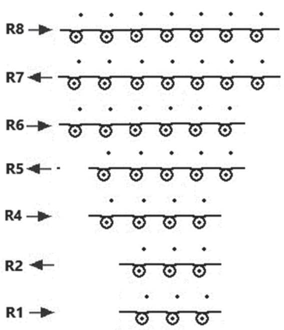
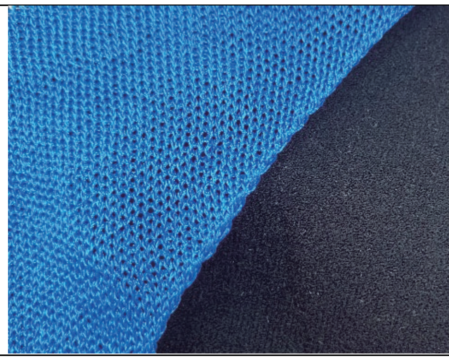
3. Choosing the suitable knitting technique

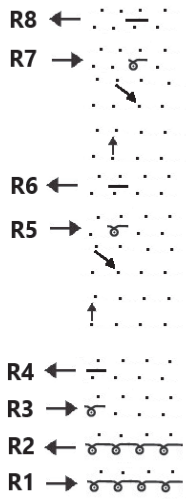
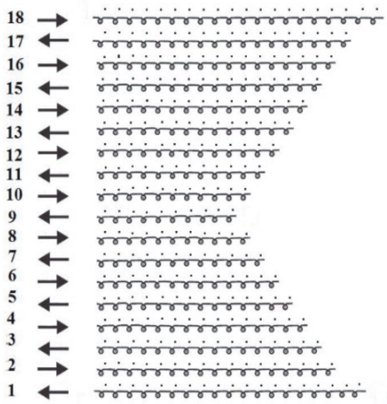
The product requirements must be used to determine which techniques are suitable for meeting the design requirements. On flatbed knitting machines, one area can be knitted on each needle bed. Depending on the end product, these needle beds can work individually or together. There are various knitting techniques and structures that can be used to produce 3D knitted fabrics: Tubular knitting, spacer structures, inlay (i.e., inserting threads between two corresponding knitted layers), jacquard, plating technique, multigauge, DOS (Directional Oriented Structures), narrowing and widening techniques, cast-off, and partial row knitting (goring) (Table 1). According to the design requirements in terms of shape, dimensions, aesthetic and functional properties, one or a combination of techniques can be chosen.

Table 1

List of different knitting techniques used for shaping

Knitting technique	Row section	Knitted fabric
Tubular knitting	 [16]	 [16]

Knitting technique	**Row section**	**Knitted fabric**
Spacer structures	 [16]	 [16]
Inlay	 [14]	 [14]
Plating		 Front side Back side
Narrowing		
Widening		

Knitting technique	Row section	Knitted fabric
Bind-off		
Partial kitting	 [16]	 [16]

For the example shown in the previous steps, the partial row knitting technique was used for contouring based on an interlock knit structure (Figure 3).

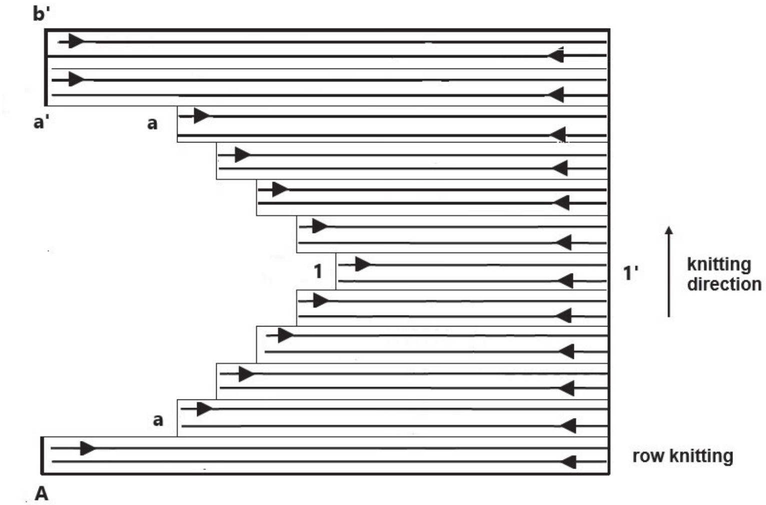


Figure 3. Knitting technique details [16]

4. Knitting machine selection

It is necessary to select the appropriate knitting machine suitable for the production of the concept, taking into account its design features (gauge, number of needle beds, dimension of the needle bed, number of yarn guides, type of yarn guides, type of take-off mechanism, distance between needle beds, yarn pressing mechanism, etc.), which leads to its technical capabilities.

5. Setting-up the knitting parameters

This is the step where the parameters of the knitted fabric must be determined. Depending on the specifics of the yarn (yarn thickness, texture), knitting techniques and the capabilities of the knitting machine, the appropriate parameters must be determined. They determine the final result in terms of feasibility. Small knitting samples must be made to test the requirements (knittability of the yarn, stitch density, formability, stability of the knit, elasticity, shrinkage after knitting, etc.)

6. Creating the 2D shape on the CAD system

There are several ways on the CAD knit design system to create a shape. Two of the most convenient methods are: using the existing design tools and options to draw the outline of the shape, or importing a pattern previously created with special pattern creation software as the shape. The first technique requires detailed dimensional information about each component of the product and a technical sketch that has various specifics about structure and shape that the programmer must consider. The second technique involves a mold that is built using special pattern software with the appropriate dimensions of the final product. By entering the stitch density values during the import process of this vectorial shape, an accurate shape is obtained that the programmer can use to build specific knitted areas. The following example shows the construction of the method directly in the software CAD (Figure 4) with the specified dimensions and stitch density (number of rows and wales per 10 cm).

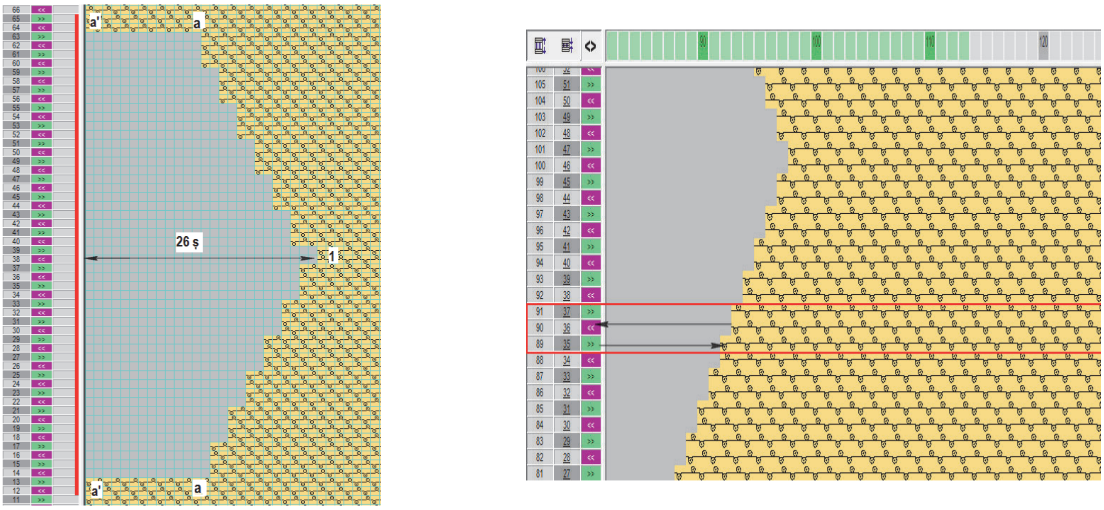


Figure 4. Shape construction directly on the Stoll M1plus® CAD software [16]

7. Building-up the knittable program

Once the form has been established, it is time to apply the chosen techniques in each specific area. Depending on the skills and knowledge of the programmer, these areas can either be created directly on the form or simply imported from a database previously created and stored in the computer (Figure 4). This step also includes setting the technical parameters required for the knitting process (Figure 5). Further changes to the parameters can also be made directly on the knitting machine.

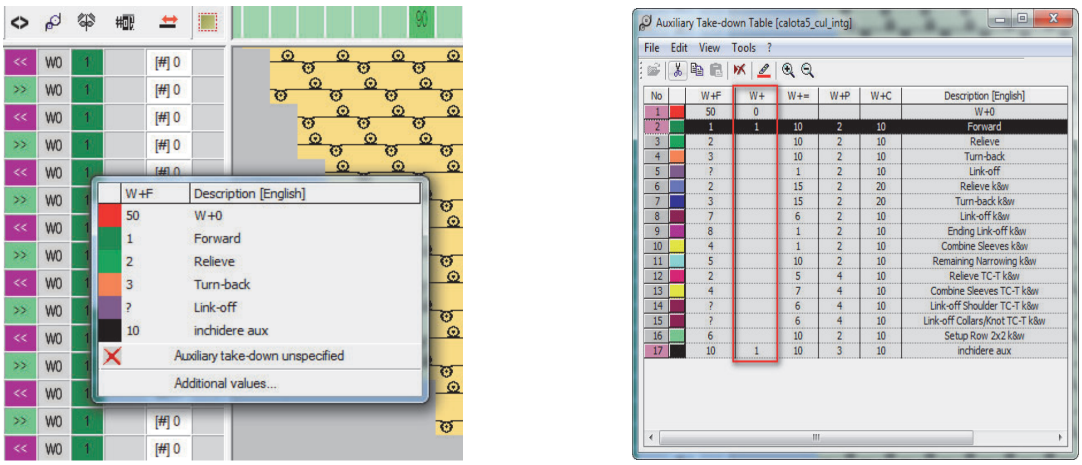


Figure 5. Setting-up the take-down mechanism [16]

8. *Testing the knittability of the program*

As each step is completed, the entire buildup program must be tested on the computer and then put into practice and tested on the machine. This is the step where the necessary changes can be made, depending on whether and what the knitting machine is capable of producing according to the designed program (Figure 6). The final goal is to obtain a correct knitted and optimized model.

Figure 6. The knitted shape [16]

3. USES OF THE 3D KNITTED SHAPES

The knitwear industry is a remarkable field and 3D knitting is a phenomenon that is constantly growing in terms of consumption. The technical textiles market is the sector that has the greatest impact. It brings benefits to the circular economy by offering different materials that can be reused as raw material for production or upholstery, such as polyester yarn recycled from marine bottles and used for furniture upholstery [17]. Another contribution of this technology is the sustainability factor. Shape knitting, integral knitting and 3D knitting shapes make this technology one of the most sustainable products as it can be produced efficiently and without waste.

The technology of 3D knitting allows the production of products combining in a single material different technique on the same machine, which increases creativity in terms of aesthetics, but also produces products with parts with different functional properties. This technology allows the production of fully fashionable sports tops, knitted pockets for electronic devices [18], products with integrated sensors for biomechanical monitoring [19], shock-absorbing products such as sports helmets or shoulder pads [20], soft robotic assistive parts [21], artificial heart valves, knitted goods for drug delivery, ribbons, medical socks [22], sensor gloves, knitted shoes, knitted pipes for thermal insulation [6].

4. CONCLUSIONS

Knitted materials have become a focus of interest for engineering research due to the ability to incorporate engineered yarns into various structures and their ability to create a range of shapes directly from the knitting machine with minimal or no further processing. Knitting technology has the great advantage of being able to transform a digital design into a true finished product without the need for an additional process of cutting and sewing. By using different knitting methods, structures and yarns, products can be designed that are suitable for high-performance applications.

Technical products are known to be expensive, especially the high cost of technical yarns. The knitting industry is considered to be the technology that can reduce manufacturing costs, as it is possible to create products without waste, such as seamless knitted fabrics, 3D shaped products or through the possibility of reusing the yarn, which is also the main basis for a sustainable product.

CAD systems play an important role in the knit design process. It provides the necessary interface to translate a conceptual design into a feasible knit. Knitting education needs to adapt the learning process to the real needs of the industry. Digitalization in the textile industry provides the appropriate tools to enable faster product design for sustainable manufacturing.

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THE IMPACT OF THE STRUCTURE AND DYNAMICS OF RESOURCES ON FINANCIAL PERFORMANCE

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Abstract. *One of the challenges facing companies is the efficient use of their resources. The few research on this topic has provided mixed results, which requires further analysis to shed light on the interdependencies between resource use and business performance. The aim of this study was to perform a comparative analysis to answer the following research question: how can performance be improved? In order to perform the analyses, secondary data were collected for the period 2010-2022. Based on the econometric analyses that used panel data, the aim was to assess the extent to which the volume and dynamics of human, material and financial resources influence the size and dynamics of performance, measured based on return on assets (ROA) and return on equity (ROE). The performance analysis indicated that the volume of advanced resources in economic activity is very important for companies engaged in textile, car and construction materials trade. The analysis at the level of resource types indicated the following: the increase in the volume of fixed assets negatively influences the performance; the increase in the volume of current assets and human resources has a positive impact only on the performance of companies engaged in car trading; the use of own financial resources has a mixed impact on performance; the intensification of the use of financial resources procured through indebtedness has negative effects on performance; the positive impact of resource use efficiency was significant only for one of the two analysed indicators (labour productivity); analyses at the level of resource dynamics confirmed the negative impact of indebtedness on financial performance. The results of this study are theoretically useful (because they provide additional evidence on the interdependence between resources and performance), but also practically (because they provide support for managers to adopt investment policies that are favourable to increasing financial performance).*

Keywords: *financial performance, types of resources, the efficiency of resource use, commerce, information technology consultancy.*

1. INTRODUCTION

The present study capitalises the results of previous research and extends the analysis of the interdependencies between resource utilization and corporate performance. Performance is an indicator that quantifies the consequences of various managerial decisions that materialized in investments, financing operations, and using of the current resources [1].

Studies on the determinants of financial performance of Romanian companies are relatively scarce. For example, some authors [2] examined the most important determinants of financial performance assessed through four types of indicators (profit margin, profit growth rate, return on assets, return on equity, and economic value added). Conducting the analysis on a sample of companies from the automotive industry (for the period 2010-2019), the authors demonstrated that the sales growth rate is a significant determinant of financial performance, and company size (evaluated by total assets) has a positive influence on profit margin and economic value added. Other researchers [3] investigated the profitability determinants of listed Romanian companies for the period 2000-2011. Using fixed-effects regression models (to simultaneously consider industry-specific characteristics and time effects), the authors showed that the share of tangible assets in total assets, the leverage effect (total debt to total assets ratio), size (total assets), and labour intensity have a negative effect on firm performance. Instead, sales growth had a positive effect.

Pantea et al. (2014) [4] analysed a sample of 55 listed Romanian companies and found that there is no statistically significant relationship between sales growth rate and financial performance as measured by return on assets (ROA) and return on equity (ROE). Instead, the authors demonstrated a positive relationship between capital intensity (defined as the proportion of fixed assets in total assets) and human resources on one hand, and financial performance (ROA and ROE) on the other.

Given the mixed results of previous studies (and the lack of focus on unlisted companies), this present study aims to assess the extent to which the volume and dynamics of resource used (material, human, and financial) influence the magnitude and dynamics of performance, measured by two established indicators: ROA and ROE. The category of performance determinants included the volume of resources (evaluated through the size of fixed and current assets, the number of employees, the size of equity, and debt size), resource utilization efficiency (evaluated through the sales growth rate and labour productivity), and the level of indebtedness. The arguments for selecting these determinants originates from international debates. Both manufacturing and service companies have two categories of material resources. The first category consists of fixed assets, which have high values and are used by companies for an extended period (such as buildings, land, equipment, vehicles, etc.). In the case of manufacturing companies, fixed assets represent a significant proportion of total assets. Acquiring these resources involves the use of long-term financial resources. The second category comprises current assets (inventory, receivables, and cash), which are available to the company for a shorter period of time. Unlike fixed assets, which are available to companies for a longer period, current assets are used in a single production cycle. In the case of service companies (such as those in the retail sector), the volume of the current assets is greater than the volume of fixed assets.

Acquiring both types of resources involve expenses for the company. However, their efficient exploitation contributes to financial results, forming the basis for assessing financial performance. Therefore, it is the responsibility of managers to establish an optimal volume of assets that, when efficiently exploited, contributes to improved financial performance. Oversizing the resources has the effect of creating immobilizations, while under-sizing the resources disrupts the internal operations of companies due to insufficient production factors.

Some authors [5] have been concerned with determining which of the two types of assets contributes more significantly to net profit. They assessed the volume of assets by weighting it with sales volume, for a sample of 28 companies in three industries (food, construction, and petrochemical), for the period 2008-2012. Regarding the interdependence between assets (fixed and current assets) and performance (evaluated by ROA), the authors' research did not provide statistically significant data. However, assets were found to have an influence on ROE (only in the petrochemical sector).

Osamor et al. (2021) [6] showed that the efficient utilization of assets is a precondition for maximizing revenue and achieving a reasonable level of performance. Specifically, by analysing the behaviour of a sample of companies in the oil and gas sector (for the period 2007-201 9), their study did not identify a statistically significant relationship between fixed assets and performance (assessed by profit before interest and tax). Instead, the authors showed that the use of current assets significantly impacts performance. In contrast to the results of the previously mentioned authors, the analyses conducted by Gladys and Job (2017) [7] on a sample of listed companies in the commerce and service sector indicated that fixed assets had an impact on financial performance, while current assets did not significantly affect financial performance (assessed by indicators such as earnings per share, return on assets, return on equity, and profit margin).

Research focused on the contribution of human resources to performance consolidation has employed various indicators, such as the average number of employees or labour intensity. These studies have provided mixed results. Some studies [4] have offered evidence of the positive impact of the number of employees on performance measured by ROA and ROE. Other authors [3] have provided evidence of an inverse relationship between labour intensity and performance (ROA).

In a case study conducted on a Romanian company in the ferrous metal production sector, Stănescu et al. (2018) [8] tested the link between human resources (specifically, the number of employees) and financial performance (measured by turnover, total revenue, and net profit). They showed that there is a direct and statistically significant relationship between the number of employees and the dynamics of total revenue, but the number of employees does not influence the volume of profit.

Siminica et al. (2019) [9] developed a new performance measurement system and analysed the interdependencies with financial indicators such as ROA, sales growth, the average number of employees, etc. The results of their study confirmed the positive relationship between performance indicators and the number of employees. The authors explained that companies with superior human resources (both quantitatively and qualitatively) have the capacity to create additional market value.

Despite extensive debates on the structure of financial resources used by companies, research results are not convergent. Some studies have provided evidence of the negative impact of borrowed resources on financial performance [2, 3, 10, 11], confirming the packing order theory postulate. Other studies have provided contrary evidence, confirming the trade-off theory postulate [12, 13]. Other authors [14] have emphasized that managers must simultaneously address two issues: the purchase and efficient use of assets, as well as their financing. Using a sample of companies listed on the Bucharest Stock Exchange (for the period 2017-2021), they analysed the relationship between performance (ROA and ROE) and capital structure (assessed by debt-to-assets, debt-to-equity, and debt-to-permanent capital ratios). Their results revealed that there was no statistically significant relationship between debt-to-assets and performance. However, debt-to-equity and debt-to-permanent capital ratios significantly influenced ROA and ROE (with a stronger influence observed on ROE). Brendea et al (2022) [15] investigated the relationship between capital structure and firm performance. Based on a sample of non-financial companies from eight countries in Central and Eastern Europe, they tested the impact of capital structure (debt ratio) on firm performance, and their results indicated a negative relationship between the two selected variables.

Also, in the list of performance determinants is the sales growth rate. Although it is hypothetically assumed that an increase in sales is a premise for improved performance, research results for this variable are mixed. Some authors have identified a positive relationship [2,3], while others have not found a statistically significant relationship between the two variables [4, 16].

2. EXPERIMENTAL PART

The motivation for choosing the research topic is based on the premise that Romanian companies from various industries present different levels of performance, and the determinants of performance vary from one industry to another. The purpose of this study is to analyse the impact of the resource use (material, human, and financial) on the companies' performance. The efficiency of using these resources translates into the magnitude and dynamics of the recorded performances. To add value to scientific research, a comparative analysis was conducted in the following industries: information technology (IT) consulting activities; trade in textiles, fur clothing, footwear, and leather goods (TT); trade of construction materials and sanitary equipment (CT); trade of automobiles and spare parts (AT).

To ensure data homogeneity, the criterion used to create the sample was the size and dynamics of financial results. Initially, based on the criterion of profit size recorded in 2022, 12 companies from the IT sector, 15 companies from the TT sector, 10 companies from the CT sector, and 10 companies from the AT sector were selected. From the initial sample of 47 companies, companies that recorded losses for the period 2010-2022 were eliminated. The final sample consisted of 20 companies, with 5 from each sector. The majority of the selected companies (85%) are not listed on the stock exchange, which is why the data were collected from secondary sources (annual financial statements).

Since companies in the four indicated sectors have their own specific characteristics, analyses were conducted on two levels: the first set of analyses was conducted at the overall sample level, and the second set of analyses was conducted on four pilot samples. The variables analysed were organized as follows: a) dependent variables: return on assets (ROA) and return on equity (ROE); b) independent variables reflecting the volume of resources engaged: material resources represented by fixed assets (FA) and current assets (CA); human resources, evaluated by the number of employees (NE); financial resources, represented by equity (OC) and debts (D); c) independent variables reflecting the dynamics of resources engaged, i.e., the efficiency of their use: turnover growth rate (Tgr), asset growth rate (Agr), degree of indebtedness (DI), and labour productivity.

For the econometric analysis, the Data Analysis package in Excel was used. Correlation and regression analyses adapted to the panel data model were run. These analyses were conducted for both the entire sample and the four sub-samples. The results and discussions are presented in the following section.

3. RESULTS AND DISCUSSION

Descriptive statistics represented the first step of the analyses. The aim was to identify the data characteristics at both the sample level and the selected sectors levels. According to the data in Table 1, the average profitability for the entire sample was 21.1% (ROA) and 37.8% (ROE). However, the analysis at the sub-sample level reveals that the IT sector exhibits higher profitability compared to the other sectors. The lowest levels of economic profitability (ROA and ROE) were recorded by companies in the CT sector, even though this sector had the highest volumes of material resources (FA and CA) and equity (OC). Additionally, the CT sector stands out for having the highest levels of borrowed resources used (D) and a large number of employee (NE). Regarding the distribution of values for the dependent variables (for the entire sample), the minimum-maximum range for ROA and ROE varies between 0.1% and 103.3%, indicating that the companies in the sample are not comparable in terms of performance. Comparable size gaps are also observed among companies in the IT and TT sectors (including AT, only for ROE). Companies in the CT sector had a more modest minimum-maximum range (between 1.0% and 24.4% for ROA and 53.1% for ROE), suggesting that companies in this sector are more homogeneous in terms of their recorded performance.

Table 1

Descriptive statistics

	Whole sample (resources)							**IT sample**						
	ROA	**ROE**	**FA**	**CA**	**OC**	**D**	**NE**	**ROA**	**ROE**	**FA**	**CA**	**OC**	**D**	**NE**
Mean	21.1	37.8	74.1	121.7	74.1	88.7	353.9	32.6	52.4	8.4	49.8	27.6	28.6	522.3
Median	13.6	24.8	25.1	32.0	25.1	17.6	89.5	28.1	57.1	1.2	15.6	9.3	9.6	89.0
St. Dev.	21.9	31.3	141.6	190.5	141.6	154.2	767.6	26.6	29.2	13.5	66.4	40.1	38.8	999.2
Min.	0.7	0.1	0.0	0.2	0.0	0.2	0.1	2.6	1.2	0.0	0.2	0.0	0.2	1.0
Max.	103.3	100.0	885.7	1083.7	885.7	677.4	3291.0	103.3	100.0	48.6	206.0	133.0	119.3	3291.0
Count	260	260	260	260	260	260	260	65	65	65	65	65	65	65
	TT sample							**CT sample**						
	ROA	**ROE**	**FA**	**CA**	**OC**	**D**	**NE**	**ROA**	**ROE**	**FA**	**CA**	**OC**	**D**	**NE**
Mean	24.5	35.6	9.1	10.5	13.6	5.8	45.2	12.2	19.1	166.0	157.7	162.2	161.7	682.8
Median	12.6	19.6	1.5	7.4	5.5	3.1	41.0	13.4	18.4	20.0	46.8	39.9	25.3	174.0
St. Dev.	27.8	34.5	13.9	11.1	16.4	5.9	35.4	6.5	10.0	290.0	215.8	241.2	243.1	1041.4
Min.	0.7	0.8	0.0	0.2	0.0	0.2	7.0	1.0	1.6	5.6	8.5	7.3	1.0	73.0
Max.	99.2	99.1	43.5	47.5	54.0	22.8	161.0	24.4	53.1	794.6	832.0	885.7	677.4	3169.0
Count	65	65	65	65	65	65	65	65	65	65	65	65	65	65
	AT sample							**Whole sample (dynamics and resource efficiency)**						
	ROA	**ROE**	**FA**	**CA**	**OC**	**D**	**NE**		**ROA**	**ROE**	**Tgr**	**Agr**	**DI**	**LP**
Mean	15.2	44.3	22.9	268.9	93.1	158.6	165.4		21.1	37.8	1.2	1.2	48.1	13.7
Median	10.1	34.1	23.1	173.4	68.1	118.5	93.0		13.6	24.8	1.1	1.1	47.5	13.4
St. Dev.	12.6	34.7	14.7	233.9	83.1	120.5	170.1		21.9	31.3	0.4	0.4	23.0	1.6
Min.	1.1	0.1	2.0	60.4	1.6	15.0	0.1		0.7	0.1	0.5	0.6	2.1	10.6
Max.	46.3	99.5	57.0	1083.7	414.0	497.1	579.0		103.3	100.0	4.0	5.1	99.2	23.4
Count	65	65	65	65	65	65	65		260	260	260	260	260	260

Source: Own preparation.

Note: In this table, material and financial resources (FA, CA, OC and D) are in millions of monetary units. For the subsequent statistical processing (in order to apply linear regression) the natural logarithm of these variables was determined.

Regarding the dynamic indicators, the data in Table 1 reveals that the average sales growth rate is equal to the average asset growth rate (1.2). The analysis at the sub-sample level found that this situation holds for the IT and TT sectors. However, for companies in the CT sector, the average asset growth rate was higher than the average sales growth rate. This situation can be explained by the growth strategy (an increase in the number of construction materials sales points was recorded during the period 2010-2022).

The average degree of indebtedness of companies in the sample is 48.1%. The analysis on pilot samples revealed that companies in the AT sector have the highest level of indebtedness (61.1%). This can be attributed to the nature of the goods sold. Automobiles have high values, which require companies to rely on loans to ensure cash flow. Companies in the IT sector have an average degree of indebtedness of 50.9%, while companies in the TC and TT sectors have degrees of indebtedness of 44.2% and 36.3%, respectively.

The annual average labour productivity is very close to the median, indicating that there is more homogeneity in the data for this variable. The lowest labour productivity was recorded in the TT sector

(10.6 million m. u. per employee), while the highest value was recorded in the AT sector (23.4 million m. u. per employee). In the IT and CT sectors, the recorded average values were 15.4 million m. u. per employee.

The second step in the econometric analysis involved evaluating the statistical relationships and associations between the data related to the model's variables. Correlation analyses were conducted using the Pearson correlation coefficient (Table 2).

Table 2
Correlation analysis

	Whole sample (resources)											**IT sample**										
	ROA	**ROE**	**FA**	**CA**	**NE**	**OC**	**D**	**Tgr**	**Agr**	**DI**	**LP**	**ROA**	**ROE**	**FA**	**CA**	**NE**	**OC**	**D**	**Tgr**	**Agr**	**DI**	**LP**
ROA	1											1										
ROE	0.7	1										0.8	1									
FA	-0.4	-0.4	1									0.0	0.1	1								
CA	-0.2	0.0	0.8	1								0.0	0.1	0.9	1							
NE	-0.2	-0.2	0.7	0.7	1							0.1	0.1	0.9	0.8	1						
OC	-0.2	-0.3	0.9	0.9	0.7	1						0.2	0.2	0.9	1.0	0.9	1					
D	-0.4	-0.1	0.8	0.9	0.7	0.8	1					-0.2	0.0	0.9	1.0	0.8	0.9	1				
Tgr	0.2	0.2	-0.2	-0.1	-0.1	-0.1	-0.1	1				0.0	0.1	-0.1	0.0	-0.2	-0.1	0.0	1			
Agr	0.2	0.1	-0.2	-0.1	-0.1	-0.1	-0.1	0.6	1			0.0	0.0	-0.2	0.0	-0.2	-0.1	0.0	0.4	1		
DI	-0.4	0.2	0.0	0.2	0.1	-0.1	0.5	0.1	0.0	1		-0.7	-0.3	-0.1	0.0	-0.2	-0.3	0.2	0.2	0.1	1	
LP	-0.1	0.1	0.4	0.7	0.1	0.5	0.6	0.0	0.0	0.3	1	0.0	0.2	-0.1	0.2	-0.4	0.0	0.2	0.4	0.2	0.4	1
	TT sample											**AT sample**										
ROA	1											1										
ROE	0.9	1										0.4	1									
FA	-0.7	-0.7	1									0.2	-0.1	1								
CA	-0.4	-0.4	0.6	1								0.6	0.5	0.4	1							
NE	-0.5	-0.5	0.4	0.4	1							0.1	0.1	0.5	0.0	1						
OC	-0.4	-0.6	0.8	0.8	0.4	1						0.6	-0.3	0.4	0.5	0.0	1					
D	-0.7	-0.7	0.8	0.9	0.5	0.8	1					0.3	0.7	0.5	0.8	0.2	0.1	1				
Tgr	0.3	0.3	-0.2	0.0	0.0	-0.1	-0.1	1				0.1	0.1	0.0	0.0	-0.1	0.0	0.0	1			
Agr	0.3	0.2	-0.2	0.0	-0.1	-0.1	-0.2	0.7	1			0.1	0.1	0.2	0.3	0.1	0.1	0.4	0.4	1		
DI	-0.2	0.2	-0.3	-0.2	0.0	-0.6	0.1	0.0	-0.1	1		-0.3	0.6	0.2	0.2	0.2	-0.6	0.7	0.0	0.2	1	
LP	0.0	-0.1	0.4	0.7	-0.2	0.6	0.5	0.1	0.1	-0.4	1	0.4	0.1	0.2	0.6	-0.4	0.5	0.4	0.0	0.1	-0.1	1

Source: Own preparation.

Note: The results of the correlation analysis for the data related to the companies in the CT field are similar to the results at the level of the entire sample.

Since the correlation analysis indicated strong associations between FA, CA, NE, OC and D, the regression models were built to avoid including these variables in the same model. Multiple regression analysis was used to examine the interdependence between selected variables. The regression models proposed to be tested (both at the level of the extended sample and at the level of the pilot samples) are:

$$M1: ROA\ (ROE) = \beta_1 \bullet FA \pm \beta_2 \bullet Tgr \pm \beta_3 \bullet Agr \pm \beta_4 \bullet DI \pm \beta_5 \bullet LP \pm \varepsilon i \qquad (1)$$

$$M2: ROA\ (ROE) = \beta 1 \bullet CA \pm \beta 2 \bullet Tgr \pm \beta 3 \bullet Agr \pm \beta 4 \bullet DI \pm \beta 5 \bullet LP \pm \varepsilon i \qquad (2)$$

$$M3: ROA\ (ROE) = \beta 1 \bullet NE \pm \beta 2 \bullet Tgr \pm \beta 3 \bullet Agr \pm \beta 4 \bullet DI \pm \beta 5 \bullet LP \pm \varepsilon i \qquad (3)$$

$$M4: ROA\ (ROE) = \beta 1 \bullet OC \pm \beta 2 \bullet Tgr \pm \beta 3 \bullet Agr \pm \beta 4 \bullet DI \pm \beta 5 \bullet LP \pm \varepsilon i \qquad (4)$$

$$M5: ROA\ (ROE) = \beta 1 \bullet D \pm \beta 2 \bullet Tgr \pm \beta 3 \bullet Agr \pm \beta 4 \bullet DI \pm \beta 5 \bullet LP \pm \varepsilon i \qquad (5)$$

where: β – coefficients of regressions; εi – free terms.

According to the ANOVA test, applied to the data of the entire sample, all five regression models have been statistically significant. The results indicated that financial performance (evaluated by ROA and ROE) is negatively influenced by the volume of resources employed (FA, CA, NE, OC, D) because they generate costs, reducing financial results (which underpin financial performance). However, performance is positively influenced by Tgr (sales growth rate) and LP (labour productivity).

According to the data in Table 4, the performance of companies in the IT sector is negatively influenced by the degree of indebtedness. The only factor with a positive influence on performance is labour productivity. The analysis at the volume of resources did not provide statistically significant results. Furthermore, the models with ROE as the dependent variable did not pass the ANOVA test.

Table 3

Regression analysis – whole sample

Variables	M1		M2		M3		M4		M5	
	ROA	**ROE**	**ROA**	**ROE**	**ROA**	**ROE**	**ROA**	**ROE**	**ROA**	**ROE**
Intercept	64.8*	55.1*	40.7*	14.6	33.7*	13.1	56.8*	44.9*	47.9*	29.2
FA	-4.3*	-6.2*								
CA			-2.7*	-3.0*						
NE					-1.9*	-3.5*				
OC							-3.9*	-5.8*		
D									-3.9*	-5.5*
Tgr	8.5*	12.9*	9.5*	14.7*	10.1*	15.0*	8.8*	13.2*	8.9*	13.5*
Agr	1.6	-3.5	4.8	1.2	4.5	0.5	4.3	0.3	4.1	0.1
DI	-0.4*	0.3*	-0.3*	0.3*	-0.3*	0.3*	-0.5*	0.2	-0.2*	0.5*
LP	2.1*	4.1*	2.0	3.0*	-0.3	0.5	2.6*	4.9*	2.5*	4.5*
R Square [%]	36	27	22	11	21	12	27	18	26	17
Adjusted R Square [%]	34	25	21	10	19	10	25	16	25	15
Sig. F - ANOVA	$2*10^{-22}$	$1*10^{-15}$	$2*10^{-12}$	$10*10^{-6}$	$2*10^{-11}$	$3*10^{-6}$	$1*10^{-15}$	$1*10^{-9}$	$2*10^{-15}$	$9*10^{-9}$

Source: Own preparation. Note: * statistically significant 95%.

On the other hand, the analysis at the level of dynamics and efficiency resource highlighted a negative impact of indebtedness and a positive impact of labour productivity only on performance measured by ROA.

Table 4

Regression analysis (I)

Variables	IT sample									TT sample										
	M1		M2		M3		M4		M5	M1		M2		M3		M4		M5		
	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE
Intercept	-22.3	-	-26.6	-	-38.2	-114.4	-23.8	-	-24.0	-	137.2*	133.2*	42.8	15.9	171.9*	176.7*	119.7*	108.6*	83.4*	64.9
FA	-0.6	-		-				-		-	-12.0*	-15.1*								
CA		-	-0.5	-				-		-			-16.0*	-19.0*						
NE		-		-	0.4	2.3		-		-					-17.0*	-21.3*				
OC		-		-			-0.6	-		-							-16.3*	-19.8*		
D		-		-				-	-0.7	-									-19.2*	-23.6*
Tgr	6.6	-	6.4	-	6.6	7.4	6.3	-	6.2	-	13.7*	21.5*	8.6	15.1	12.3	19.7	8.4	15.0	8.8	15.4
Agr	-0.4	-	0.0	-	0.2	-5.0	-0.1	-	-0.1	-	-10.8*	-19.5*	3.9	-0.8	2.5	-2.8	0.0*	-5.6	-1.2	-7.2
DI	-1.1*	-	-1.1*	-	-1.1*	-0.5*	-1.1*	-	-1.1*	-	-0.7*	-0.2	-0.2	0.4*	-0.4*	0.1	-0.9*	-0.4*	0.0	0.7*
LP	8.4*	-	8.7*	-	8.8*	13.9*	8.6*	-	8.7*	-	6.5*	9.9*	17.8*	22.6*	-7.3*	-7.4	14.4	19.1*	17.5*	23.1*
R Square [%]	56	-	56	-	56	18	56	-	56	-	84	81	46	62	44	41	66	60	76	70
Adjusted R Square	52	-	52	-	52	11	52	-	52	-	82	81	41	39	40	36	63	56	74	67
Sig.. F ANOVA	$2\cdot10^{-9}$	0.06	$2\cdot10^{-9}$	0.06	$2\cdot10^{-9}$	0.03	$2*10^{-9}$	0.05	$2\cdot10^{-9}$	0.05	$6\cdot10^{-22}$	$5\cdot10^{-20}$	$6\cdot10^{-7}$	$2\cdot10^{-5}$	$1\cdot10^{-6}$	$7\cdot10^{-6}$	$9\cdot10^{-13}$	$2\cdot10^{-10}$	$7\cdot10^{-17}$	$3\cdot10^{-14}$

Source: Own preparation.
Note: * statistically significant 95%.

For companies in the TT sector (Table 4), all resources (material, human, and financial) utilized in economic activity had a statistically significant negative impact on financial performance as measured by ROA and ROE. The sales growth had a positive impact on performance only in the model that combines the analysis at the level of fixed asset volume and dynamics. Similar to companies in the IT sector, indebtedness was found to have a negative impact, while labour productivity had a positive impact.

Similar to companies in the TT sector, companies in the CT sector experienced a decline in performance due to the volume of resources utilized (Tabel 5). A particular aspect worth noting is the contribution of the fixed asset growth rate (Agr) to the improvement in performance as measured by ROE. For this sample, the negative impact of indebtedness is no longer so significant (this being statistically significant only for models that had ROA as the dependent variable). The positive impact of labour productivity was statistically significant in only two out of the five tested models.

The final tests were conducted for companies in the AT sector (table 5). Unlike the analyses in other sectors, the analyses in this case revealed: a) positive associations between resource volume and financial performance; b) negative interdependencies between asset growth rate and performance; c) positive associations between ROA and indebtedness and negative associations between ROE and indebtedness.

Table 5
Regression analysis (II)

Variables	CT sample										AT sample									
	M1		M2		M3		M4		M5		M1		M2		M3		M4		M5	
	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE	ROA	ROE
Intercept	-2.6	-44.3	-11.4	-57.4*	-7.2	-51.4*	-8.4	-53.2*	-11.5	-57.7*	-66.8*	11.9	-220.0*	-479.7*	-95.1*	-118.1	-146.0*	-159.9	-217.4*	-397.7*
FA	-1.1*	-1.7*									2.2	-8.6*								
CA			-1.3*	-1.7*									14.0*	28.7*						
NE					-1.3*	-1.9*									6.6*	1.5				
OC							-1.1*	-1.6*									8.0*	4.0		
D									-1.0*	-1.4*									15.0*	24.4*
Tgr	6.1	10.4	6.5	11.1	6.6	11.2	6.3	10.8	6.6	11.2	6.6	14.0	11.5	33.5*	9.7	21.3	5.9	20.7	10.2	28.7
Agr	5.6	17.9*	6.3	19.2*	5.5	17.8*	6.0	18.7*	6.2	18.9*	2.2	-4.9	-8.6	-39.9*	0.5*	-14.2	-3.6	-17.4	-9.6	-36.0*
DI	-0.2*	0.0	-0.2*	0.0	-0.2*	0.0	-0.2*	0.0	-0.2*	0.1	-0.2*	1.1*	-0.3*	0.9*	-0.2*	1.0*	0.1	1.2*	-0.5*	0.4*
LP	2.1	4.3	2.9*	5.3*	1.6	3.4	2.6*	4.9*	2.4	4.6	3.0*	6.2*	-1.3	-4.6	5.1	5.3	0.7	3.5	-0.9	-2.0
R Square [%]	81	54	64	52	64	52	65	53	64	52	25	49	63	67	38	45	41	46	54	56
Adjusted R Square	66	50	61	48	61	48	62	49	61	48	19	45	60	65	33	41	36	41	50	62
Sig. F ANOVA	$8\cdot10^{-13}$	$5\cdot10^{-9}$	$3\cdot10^{-12}$	$2\cdot10^{-8}$	$4\cdot10^{-12}$	$2\cdot10^{-8}$	$3\cdot10^{-12}$	$1\cdot10^{-8}$	$7\cdot10^{-12}$	$2\cdot10^{-8}$	$3\cdot10^{-3}$	$9\cdot10^{-8}$	$1\cdot10^{-11}$	$3\cdot10^{-13}$	$3\cdot10^{-5}$	$8\cdot10^{78}$	$7\cdot10^{-6}$	$6\cdot10^{-7}$	$7\cdot10^{-9}$	$2\cdot10^{-9}$

Source: Own preparation. Note: * statistically significant 95%.

A summary of the results obtained is presented in Table 6. The results of the conducted analyses are highly useful and provide evidence regarding the interdependencies between resources engaged in economic activities and the performance of these activities. No studies were identified in the specialized literature that were conducted specifically on the selected business sectors. Typically, research has focused on mixed samples, without taking into account the specific characteristics of different industry sectors.

Table 6
Impact of performance determinants (ROA and ROE)

Analysis level	FE	CA	NE	OC	D	Tgr	Agr	DI	LP
Whole sample	(–)	(–)	(–)	(–)	(–)	(+)	x	(–)	(+)
IT sample	x	x	x	x	x	x	x	(–)	(+)
TT sample	(–)	(–)	(–)	(–)	(–)	x	x	(–)	(+)
CT sample	(–)	(–)	(–)	(–)	(–)	x	(+)	(–)	(+)
AT sample	(–)	(+)	(+)	(+)	(+)	(–)	(–)	(+)	x

Source: Own preparation. Note: (+) positive impact; (–) negative impact; x - without influence. The synthesis was carried out taking into account the dominant result.

The negative impact of fixed assets on performance was confirmed by [4, 17]. Contrary results were provided by [5, 6, 7]. No studies were identified for the negative impact of current assets. However, studies confirming positive impact [6] or statistically insignificant impact [7, 18] have been identified. The inverse relationship between human resources and firm performance was confirmed by [3, 8]. The positive impact of human resources on financial performance was confirmed by [4, 9]. The negative effect of using own and borrowed financial resources (reflected in the capital structure or financial leverage) was confirmed by [2, 3, 9, 11]. Other studies provided evidence of positive impact [12, 13, 15] or statistically insignificant impact [14]. Regarding the interdependence between the growth rate of revenue and performance, some studies identified a positive relationship [2, 3, 19, 20].

4. CONCLUSIONS

Although debates on performance management are numerous and diverse, this study provides evidence that research topics have not been exhausted. Guided by a research question that has troubled the minds of many researchers and practitioners (how can corporate performance be improved?), this paper offers a useful answer for managers of companies providing services in the sectors of IT and in the field of trade in textiles, construction materials and cars.

From the perspective of the volume of resources engaged in different businesses, the answer to the assumed research question is different for each manager. For example, this study provides evidence for decision-makers in the TT and CT sectors, who need to limit investment volumes and efficiently use available resources to achieve superior financial performance. In contrast, the results of the study are not as useful for managers in the IT sectors because the analysis did not yield statistically significant results.

From the perspective of the dynamics and efficiency of resource utilization in different businesses, the answer to the research question has some common coordinates. Indebtedness has a negative impact on performance (for companies in all analysed sectors), increased labour productivity contributes to improved performance (especially for companies in the IT, TT, and CT sectors), the growth rate of business (reflected in revenue dynamics, Tgr) is not always a premise for performance improvement (especially for companies in the IT, TT, and AT sectors), increased investments in fixed assets are beneficial only for companies in the CT sector and partially for companies in the AT sector.

Research limitations. Given that the analysis was conducted on pilot samples, future research aims to extend the analyses to larger sample sizes. The continuation of these studies is important and has significant practical implications. Based on the evidence provided, resource managers can adjust their investment policy to minimize financial immobilization (materialized in acquisitions of material and human resources) and reduce the negative impact on performance.

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STATISTICAL RESEARCH IN HUMAN RESOURCE MANAGEMENT IN PUBLIC INSTITUTIONS

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Abstract. *Municipalities represent local public institutions in Romania and are responsible for the administration and management of affairs at the level of administrative-territorial units. The current research conducts a statistical analysis of human resources at the level of municipalities to quantitatively assess the human resource management process within an organization to achieve its objectives and ensure an efficient, motivated, and engaged workforce. The research methodology encompasses all stages of a well-founded quantitative and qualitative evaluation, including data collection, analysis of the normality of value series, formulation of working hypotheses, application of statistical tests consistent with the results obtained in the normality analysis to validate or invalidate hypotheses, correlational and inferential analyses applied to primary value series, formulation of conclusions and proposals for improving activities in these public institutions. The areas of Human Resources addressed in the research include performance evaluation at the municipality level, employee motivation and engagement, labour relations, and the impact of technology introduction in public institutions. The originality of the research stems from identifying, defining, and analyzing the variables that influence organizational activity in municipalities, from the consistent and comparative application of a statistical methodology on primary data series, and from formulating statistically validated conclusions to improve human resource organizational activities.*

Keywords: *human resource, public institutions, statistical hypotheses, statistical analyses*

1. INTRODUCTION

Human resources (HR) in public institutions refers to the personnel employed in the public sector to perform various functions and tasks within local administration or other public institutions. This human resource is essential for the smooth functioning of the administration in providing public services to citizens. Important aspects related to human resources in Public Institutions (PI) can be grouped into seven dimensions:

a. Recruitment and Selection: The recruitment and selection process is crucial to ensure that public institutions have the right personnel to fulfil their mission and objectives. This process often involves adhering to strict rules and procedures to promote transparency and impartiality.

b. Training and Development: Public institutions must provide opportunities for continuous training and development for employees so that they can improve their skills and adapt to legislative, technological, and social changes.

c. Performance Management: Regular performance evaluation of employees is essential to ensure the efficiency and effectiveness of public institutions. Performance evaluation systems can be used to recognize and reward valuable employees and identify those in need of improvements or additional training.

d. Responsibility and Ethics: Employees of public institutions must adhere to high standards of ethics and integrity, as they often manage public resources and make decisions that can significantly impact citizens and society.

e. Citizen Relations: Employees in public institutions often have direct contact with citizens and must be service-oriented, providing appropriate and timely responses to their needs.

f. Human Resource Planning: Public institutions must consider long-term human resource planning to ensure they have the necessary personnel to achieve their objectives in the future.

g. Regulations and Laws: Public institutions must comply with regulations and laws related to human resources, including those related to employment contracts, compensation, and employee rights protection.

The current research conducts a comparative statistical analysis on dimensions 1, 2, 3, and 6, analyzed in two public institutions (Figure 1).

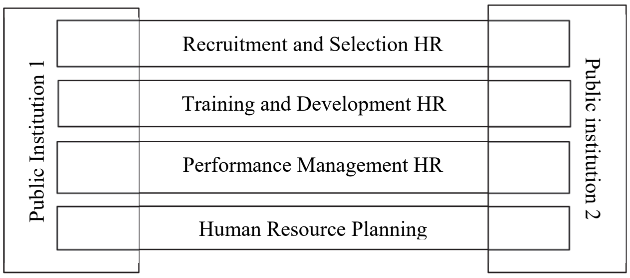

Figure 1. Dimensions of human resources analyzed and evaluated.

The motivation of the research is to find current answers regarding the state of HR from the perspective of the four dimensions in the current dynamics of the developments in public institutions.

2. MATERIAL AND METHODS

The research methodology is presented in the figure 2.

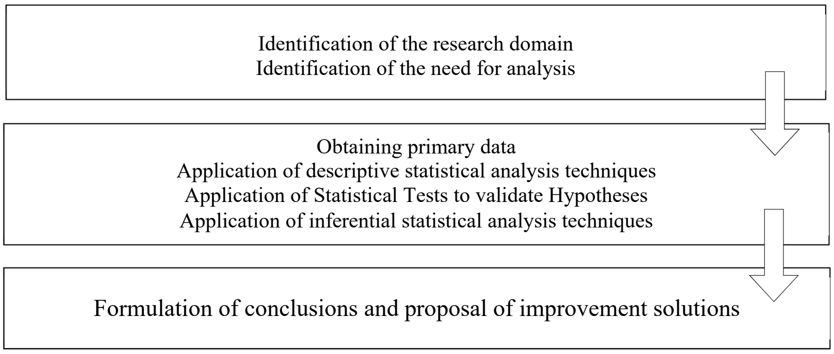

Figure 2. The research methodology

The research field is that of human resources in public institutions. This system is highly dynamic over time, with many internal and external variables influencing its nature.

The needs assessed by this research are related to organizational structure, employees' level of experience, and salary. Thus, the researched hypotheses are as follows:

Hypothesis 1: The organizational structure regarding positions in public institutions is the same.
Hypothesis 2: Salaries in public institutions are distributed statistically normally.
Hypothesis 3: There are no gender-based salary differences.
Hypothesis 4: There is a correlation between the variable "Work Experience" and "Net Salary."

The analysis and evaluation methodology includes tests for identifying the distributions of value series (Kolmogorov-Smirnov and Shapiro-Wilk normality tests), parametric and non-parametric tests for comparing value samples to validate research hypotheses, polynomial regression methods for identifying trends in the evolution of the studied indicators, and correlation methods for identifying relationships between the dimensions of the investigated phenomenon.

The clustering analysis is performed by grouping based on the personal PI characteristics of the staff in the two public institutions and applying the ANOVA method on the "Work experience" characteristic using the SPSS software program. For the analysis of the value series of statistical variables [Net Salary] and comparing their growth with indexing levels and inflation rate values during the period [2017-2022] (for which a regression polynomial of degree 3 was generated using the least squares method in MS Excel), the non-parametric Mann-Whitney U test from the SPSS environment was used.

Data structuring, statistical processing, correlation, and regression were performed using SPSS v22.0 and MS Excel Professional Plus 2019.

3. EXPLORATORY-APPLIED RESEARCH

The study was conducted in two municipalities in the northeastern region of Romania. Organizational charts and primary employee data – studies, work experience, gender, year of birth, and net salary in 2021 and 2022- were obtained.

Secondary data were collected from the websites of the two municipalities, specifically the 2011 census.

Table1.

Population Distribution in the Two Communes (PI1 and PI2) (2011 Census [1])

	Stable Pop.			0 - 14			15 - 24			25 - 34			35 - 44			45 - 54			55 - 64 ANI			65+ ANI		
	T	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T	M	F
PI1	5409	2717	2692	939	472	467	692	374	318	628	327	301	862	474	388	512	283	229	609	283	326	1167	504	663
PI2	5471	2780	2691	1079	575	504	777	416	361	686	344	342	840	446	394	615	353	262	590	281	309	884	365	519

The distribution and number of people living in the two municipalities are approximately the same, implying a similar number of needs and organizational structure.

P1 - 5 localities, 6542 hectares, 5409 inhabitants, attestation 1398 [2].

P2 - 3 localities, 3580 hectares, 5285 inhabitants, 2620 households, attestation 1453 [3].

Therefore, we expect the HR organizational chart to be the same (Table 2 and Table 3).

Table 2.

HR Structure at Municipality 1 (PI1)

IP	Name	Function	Contract	Studies	Work exp	Gender	Net salary 2017	Net salary 2022
1	N1	MAYOR	Dignitary	SL + SM	40	M	5085	6435
1	N2	VICE-MAYOR	Dignitary	SL	39	M	4068	5148
1	N3	SECRETARY	Public official	SL + SM	36	F	4018	5083
1	N4	INSPECTOR	Public official	SL + SM	17	F	2307	2918
1	N5	REFERENT	Public official	M	19	F	2172	2748
1	N6	INSPECTOR	Public official	SL + SM	28	F	2835	3586
1	N7	INSPECTOR	Public official	SL + SM	18	F	2717	3438
1	N8	COUNCILOR	Public official	SL + SM	20	M	3597	4550
1	N9	INSPECTOR	Public official	SL	29	F	2468	3124
1	N10	REFERENT	Contractual staff	M	26	F	2245	2952
1	N11	REFERENT	Contractual staff	M	19	F	2110	2807
1	N12	ACCOUNTANT	Public official	SL + SM	32	F	3977	5031
1	N13	REFERENT	Public official	M	40	M	2213	2801
1	N14	REFERENT	Public official	M	40	F	2579	3262
1	N15	GUARD	Contractual staff	G	41	M	1897	2385
1	N16	WORKER	Contractual staff	G	44	M	1745	2186
1	N17	GUARD	Contractual staff	G	39	M	1948	2453
1	N18	GUARD	Contractual staff	G	36	M	1715	2146
1	N19	DRIVER	Contractual staff	M	15	F	1697	2120
1	N20	DRIVER	Contractual staff	M	34	M	1697	2150
1	N21	DRIVER	Contractual staff	M	27	M	1543	1929
1	N22	DRIVER	Contractual staff	M	35	M	1543	1929
1	N23	DRIVER	Contractual staff	M	34	M	1694	2116
1	N24	WORKER	Contractual staff	M	33	M	2118	2682
1	N25	WORKER	Contractual staff	G	40	M	1713	2143
1	N26	WORKER	Contractual staff	G	42	M	1752	2195
1	N27	WORKER	Contractual staff	G	26	M	1760	2204
1	N28	CARETAKER	Contractual staff	G	28	F	1601	1999
1	N29	REFERENT	Contractual staff	M	33	F	1657	2071
1	N30	REFERENT	Contractual staff	M	32	F	1778	2230

Table 3.

HR Structure at Municipality 2 (PI2)

IP	Name	Function	Contract	Studies	Work exp.	Gender	Net salary 2017	Net salary 2022
2	V1	MAYOR	Dignitary	SL	35	M	5085	6435
2	V2	VICE-MAYOR	Dignitary	SL	29	M	4068	5148
2	V3	SECRETARY	Public official	SL + SM	34	M	3396	5083
2	V4	INSPECTOR	Public official	SL	28	M	2533	3124
2	V5	REFERENT	Public official	M	26	F	1442	1802
2	V6	INSPECTOR	Public official	SL	27	M	2455	3108
2	V7	REFERENT	Public official	M	31	F	1816	2282
2	V8	INSPECTOR	Public official	SL	31	F	2533	3204
2	V9	REFERENT	Public official	M	21	M	1359	1695
2	V10	REFERENT	Contractual staff	M	34	F	2433	2637
2	V11	INSPECTOR	Contractual staff	SL	33	F	1905	2395
2	V12	INSPECTOR	Public official	SL	19	F	2533	3204
2	V13	INSPECTOR	Public official	SL	12	M	1420	1774
2	V14	INSPECTOR	Public official	SL	22	M	1862	2340
2	V15	INSPECTOR	Contractual staff	SL	26	F	2302	2911
2	V16	INSPECTOR	Contractual staff	SL	26	M	1817	2281
2	V17	REFERENT	Contractual staff	M	33	M	2433	2637
2	V18	WORKER	Contractual staff	M	28	M	1745	2186
2	V19	WORKER	Contractual staff	G	25	M	1715	2146
2	V20	WORKER	Contractual staff	M	21	M	1543	1929
2	V21	WORKER	Contractual staff	M	27	M	1684	2106
2	V22	WORKER	Contractual staff	M	27	F	1695	2119
2	V23	WORKER	Contractual staff	M	20	M	1497	1867
2	V24	WORKER	Contractual staff	M	26	M	1680	2100
2	V25	WORKER	Contractual staff	M	20	M	1506	1882
2	V26	WORKER	Contractual staff	M	27	M	1647	2059
2	V27	WORKER	Contractual staff	M	31	M	1849	2324
2	V28	WORKER	Contractual staff	M	28	M	1713	2144
2	V29	WORKER	Contractual staff	M	24	F	1634	2046
2	V30	WORKER	Contractual staff	M	24	F	1634	2046
2	V31	LIBRARIAN	Contractual staff	M	34	F	2029	2542

3.1. Organizational structure in IP - clustering analysis

We are assessing the level of education through clustering analysis. For this analysis, a clustering analysis was conducted using the SPSS 22.0 software, grouping the “Study” feature based on the Public Institution's feature. The level of education of the employed and contractual personnel is different (Figure 3). This can be observed from the grouping based on educational levels. The four education levels are G=8 grades, M=12 grades, BL = bachelor's degree, and BL+ML = bachelor's and master's degrees.

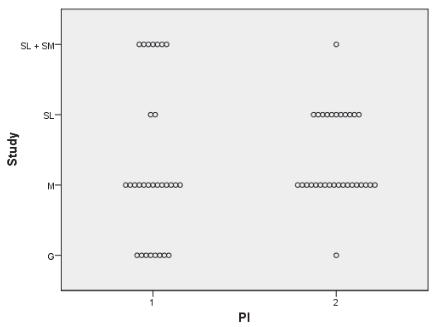

Figure 3. Grouping employees by educational levels

In PI1, the distribution is more balanced, with both bachelor's and master's degrees well represented. In PI2, the most significant cluster is for secondary education (12 grades). In summary, the 12th-grade level of education is dominant among the personnel working in public institutions.

In terms of quantity, the organizational charts are the same, but there are differences in their composition:
- Driver positions PI1=5 vs PI2=0
- Librarian PI1=0 vs PI2=1
- Worker PI1=5 vs PI2=13
- Guard PI1=1 vs PI2=0
- Accountant PI1=1 vs PI2=0

In conclusion, the roles in PI1 are more diversified and cover a wide range of activities that are functional in the normal functioning of an institution.

Another statistical evaluation was performed on the variable "Work Experience". According to Table 4 [9], it can be observed that the value series for the Work Experience feature grouped into the two dimensions of the PI feature is normally distributed (p-value=0.046 for PI1 and 0.021 for PI2). Therefore, we apply the ANOVA method [8] to compare the two value series for the WorkExperience attribute (table 5).

Table 4.

Tests of Normality

PI	Kolmogorov-Smirnov test			Shapiro-Wilk test		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
1	0.128	30	0.200*	0.932	30	0.046
2	0.122	31	0.200*	0.955	31	0.021

Table 5.

The ANOVA method

	Sum of Squares		df	Mean Square	F	Sig.
WorkExperience * PI	Between Groups (Combined)	330.799	1	330.799	6.741	0.012
	Within Groups	2895.135	59	49.070		
	Total	3225.934	60			

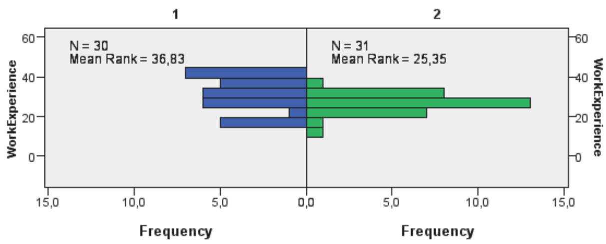

Figure 4. Work experience structure

At PI1, a personnel pattern with a higher level of experience is noticeable compared to PI2, with a superior representation in the [30-40] years of experience segment compared to the [20-30] years of experience at PI2. This leads to a better understanding and optimization of activities oriented towards the needs of citizens at PI1 compared to PI2.

3.2. Salary Level in PI - regression analysis

A first analysis of this dimension assesses the correlation between the inflation index in 2017-2022 and salary indexations during the same period. The hypothesis under examination is a positive correlation between these two indicators. Secondary data regarding the inflation index were obtained (Table 6).

Table 6.

Inflation Rate [5]

Year	Consumer Price Index [%]	Inflation Rate [%]
2017	101.34	1.3
2018	104.63	4.6
2019	103.83	3.8
2020	102.63	2.6
2021	105.05	5.1
2022	113.80	13.8

The polynomial regression curve for the inflation rate in 2017-2023 is created in the MS Excel program using the trendline function (method of least squares) [6].

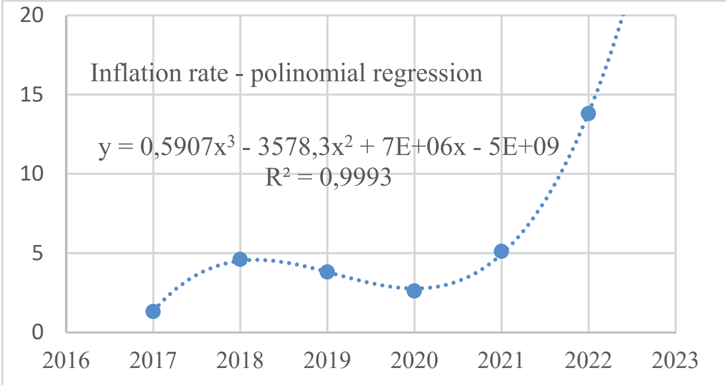

Figure 5. Inflation rate – polynomial regression

It is observed that this regression curve closely follows the values of the inflation rate (the coefficient of regression R=0.9993). Since we only have the extreme values for the analyzed interval [2017-2022] of the salaries of those working in the municipality, we will compare the total inflation rate over this period (31.2%) with the net salary increase (26.55%). By comparing these two values, we can conclude that salaries were not correlated with the inflation rate.

Furthermore. the update of salaries in public institutions is not correlated with the increase in the average salary in the economy [4] of approximately 70% (table 7).

Table 7.

Evolution of the average salary in the economy

An	Average Salary
2017	2.338 lei
2018	2.642 lei
2019	2.986 lei
2020	3.217 lei
2021	3.416 lei
2022	3.974 lei

For the variables NetSalary2017 and NetSalary2022, we will apply non-parametric tests (SPSS 22.0).

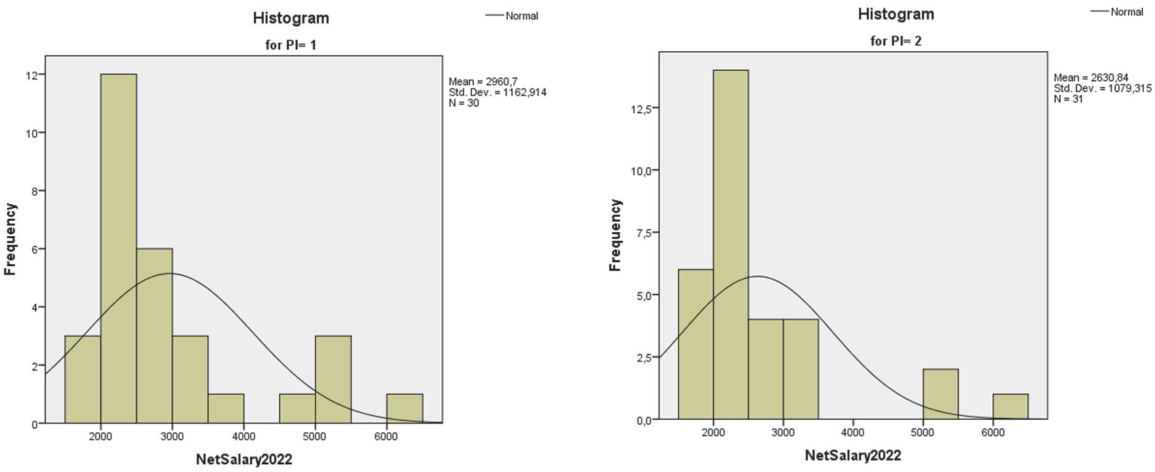

Figure 6. Frequency distribution for the variables NetSalary2022 for PI1 and PI2

What is noteworthy for the NetSalary2022 variables, both in PI1 and PI2 (Figure 6), is a significant difference between the number of low and high salaries. The median parameter value is much lower than the mean parameter value.

Another statistical hypothesis was the comparison of the means (of median ranks) of the value series with Net Salaries in 2017 and 2022 and the compositions of these series to observe the influence of external factors that impact the salary variable. The non-parametric tests Whitney-Mann U and Kolmogorov-Smirnov are applied [10]. The results are presented in Table 8 and the following figures.

Table 8.

Hypothesis Test Summary

No	Null Hypothesis	Test	Sig.	Decision
1	The distribution of NetSalary2017 is the same across categories of PI.	Independent-Samples Mann-Whitney U Test	.135	Retain H0
2	The distribution of NetSalary2017 is the same across categories of PI.	Independent-Samples Kolmogorov-Smirnov Test	.443	Retain H0
3	The distribution of NetSalary2022 is the same across categories of PI.	Independent-Samples Mann-Whitney U Test	.094	Retain H0
4	The distribution of NetSalary2022 is the same across categories of PI.	Independent-Samples Kolmogorov-Smirnov Test	.334	Retain H0

Both non-parametric Mann-Whitney U (Figure 7 and Figure 8) and K-S tests retain the null hypothesis for the value series NetSalary in 2017 and 2023 regarding the median and their distribution in the two groups PI1 and PI2. We use the SPSS 22.0 software.

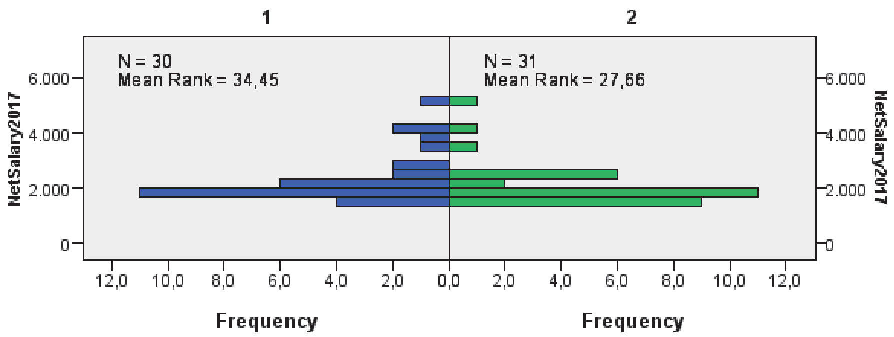

Figure 7. Test Mann-Whitney U for comparing the mean of NetSalary 2017 (PI1, PI2)

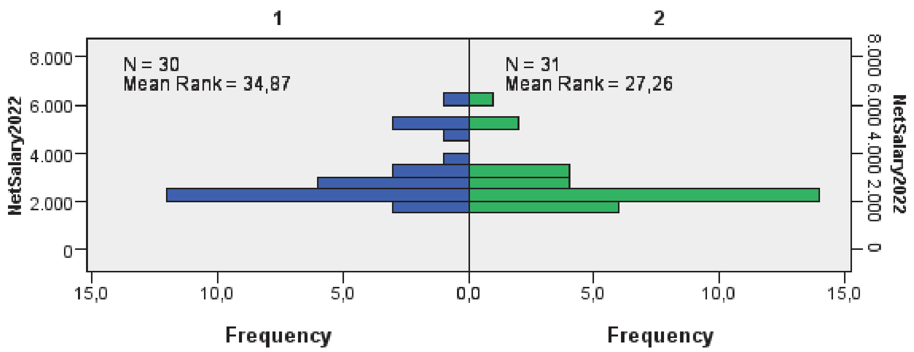

Figure 8. Test Mann-Whitney U for comparing the mean of NetSalary 2022 (PI1, PI2)

3.3. Work Experience and Net Salary - Correlation Analysis

We will study the existence of a connection between salary level and work experience. We will calculate the Pearson correlation coefficient [7] for WorkExperience, NetSalary2017, and NetSalary2022. The results are presented in Table 9. This analysis was conducted in SPSS.

Table 9.

Correlations between variables

		Work experience	GrossSalary2017	NetSalary2022
work experience	Pearson Correlation	1	0.262*	0.250
	Sig. (2-tailed)		0.042	0.052
GrossSalary2017	Pearson Correlation	0.262*	1	0.997**
	Sig. (2-tailed)	0.042		0.000
NetSalary2022	Pearson Correlation	0.250	0.997**	1
	Sig. (2-tailed)	0.052	0.000	

A statistically significant positive correlation (alpha=0.05*, alpha=0.01*) between the variables WorkExperience and NetSalary2017 (Pearson Coefficient=0.262) can be observed. This value indicates that the correlation relationship is weak [11].

The correlation coefficient value of 0.997 between the value series NetSalary2017 and NetSalary2022 is expected because the salary increases were proportional for all categories of employees. The only differences resulted from new hires during this period, with the net salary changing based on the new employee's work experience.

4. CONCLUSION. DISCUSSIONS. LIMITATIONS

The research conclusions can be summarized in the following statements:

- The structure of the organizational chart regarding the positions held in PI needs to be more balanced.
- The remuneration is undersized.
- There is no gender-based salary difference among the staff.
- Employees' education level could be higher (up to 12 grades).
- The personnel in PI is ageing, although this may signify superior experience in community activities and employee loyalty.
- There is no normally distributed salary in PI but a polarized one [meagre salaries - very high salaries], resulting in deficient public services.

The limitations of the research are related to the small number of primary data on which the research was conducted and their concentration in the northeastern region of Romania, leading to the impossibility of generalizing the conclusions formulated about the investigated phenomenon to the entire country.

The future directions of analysis focus on creating a model that encompasses the main dimensions of the Human Resources Component in public institutions, generalized across public institutions in the Northeast region and beyond at the national level.

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EVALUATION OF STUDENTS' ATTITUDE TOWARDS SLOW FASHION AND FAST FASHION IN THE CONTEXT OF ENVIRONMENTAL SUSTAINABILITY

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Abstract. *Sustainability is an approach that is increasingly being adopted by private and public organizations. Universities are starting to actively be involved in the implementation of sustainability practices and principles. The steps taken in public organisations are fewer, but they are starting to intensify. Environmental sustainability should begin with the education of students and the updating of educational plans. For this purpose, the present investigation evaluates the attitude of students toward the considerable consumption of clothes. This research analyses university students' knowledge and attitude of university students towards clothes in terms of environmental sustainability and slow fashion. Students are prone to purchase many articles of clothing and become part of the slow fashion flow. The research presents the results obtained following the quantitative evaluation of the data obtained following the participation of students in the market research carried out at the Polytechnic University of Timisoara. The main results show that students do not have a solid knowledge of slow fashion and the importance of this concept for environmental sustainability. The courses followed have been established to be tangential to sustainability and represent an important step in improving the level of knowledge.*

Keywords: *Sustainability, slow fashion, fast fashion, awareness, university, resources, consumption.*

1. INTRODUCTION

There are several issues with sustainability and social responsibility in the global fashion industry. Nowadays, fashion is more important than any other branch of the arts since it draws its inspiration from the most recent fashions. As a result, the fast fashion model of manufacturing, activities, distribution, and marketing has entered a new dimension in recent years [2]. The garment sector produces more than 92 million tonnes of garbage annually, and you use 79 trillion litres of water. These findings indicate that there is a worrying effect of fashion on the environment. Emphasis is placed on the need to the business model for the fashion industry, including a slowdown in production and the adoption of sustainable practices throughout the supply chain [1].

Therefore, universities are beginning to participate actively in the implementation of sustainability practices and principles. The steps taken in public organisations are fewer, but they are beginning to intensify. Environmental sustainability should start by educating students and also by updating the educational plan [2-7]. The research presents the results obtained following the quantitative evaluation of the data obtained following the participation of students in the market research carried out within the Politehnica University of Timisoara.

This study aims to comprehensively explore three essential aspects related to students' involvement in the fashion business. The first objective of this study is to investigate the perceptions of students about shopping and apparel, with the intention of revealing their views, preferences, and motives in relation to fashion consumption. Furthermore, this study aims to examine the purchasing patterns shown by students, specifically focussing on their shopping routines, frequency of transactions, and the determinants that impact their consumer choices in the fashion domain. Finally, the research aims to investigate the perspectives of students on sustainability in the fashion business, providing insights into their level of knowledge, apprehensions, and endorsement of environmentally conscious measures within this ever-evolving field. Through the examination of these objectives, the research aims to offer significant contributions to the understanding of the complex connection between students and the fashion industry. This includes an exploration of their perspectives, behaviors, and the growing importance of sustainability within the contemporary global fashion context.

2. RECENT CHANGES IN THE CLOTHING INDUSTRY: SLOW FASHION TO FAST FASHION

The retail industry has recently changed. The push system, in which fashion designers set trends, was fundamentally replaced by a pull system, in which retailers cater to customer needs, in the world of apparel retail. Just-in-time delivery is one concept that has been created to precisely fulfil consumer requests [1]. Industry has obstacles to sustainability. More and more companies apply sustainability concepts and achieve sustainable development objectives [8,11]. The clothing industry is a challenge in the area of sustainability. On the one hand, there are slow fashion brands that develop a sustainable culture for buyers, and on the other hand, there are fast fashion brands that develop desires and apply marketing principles to increase sales and change design lines [2-5].

2.1 Slow fashion

Slow fashion is a way of thinking about and approaching clothes that carefully analyses the resources and methods needed to manufacture clothing and places an emphasis on classic, high-quality designs and trend-driven items. It is a part of the "slow movement," which supports the production of clothing that respects people, the environment, and animals. To preserve craft and the environment, slow fashion manufacturers, consumers, and merchants work with local artisans and employ environmentally friendly materials, in contrast to the industrial practices of fast fashion companies [1].

Slow Fashion is an effort to "identify sustainable fashion solutions, based on the repositioning of design, production, consumption, use and reuse strategies, that appear alongside and potentially challenge the global fashion system" [2]. In other words, slow fashion implies resisting the rapid fashion system, which is frequently linked to detrimental effects on people and the environment, and making deliberate, environmentally friendly decisions when it comes to clothing. It encourages the buying of more durable clothing and the ethical treatment of others, including animals, people, and the environment [3].

2.2 Fast fashion

Fast fashion is a form of conception, design, production and marketing that places and launches a lot of clothes are placed and launched on the market in a short period of time. In general, low-quality materials are used to follow current trends, and products of this type have an affordable price for buyers [4].

The fast fashion business is of global interest and is part of economic development, but the overall fashion sector undermines sustainability efforts by producing 20% of the world's wastewater, according to the United Nations Economic Commission for Europe [5]. Fast fashion also contributes to roughly 10% of the world's petrol emissions. The Ellen Macarthur Foundation has released the findings of its fashion study and proposes a new circular system, which offers insight. More than 2,000 water are needed to create a t-shirt [6]. The textile sector is dominated by polyester and cotton. Cotton and polyester are the two main fibres used in textile manufacture; since 2002, polyester production has exceeded cotton production. Without halting production, fast fashion has increased textile waste, necessitating waste management [7].

3. METHODOLOGY

The purpose of this research is to evaluate the attitude of students toward the considerable consumption of clothing. The application period of this questionnaire was June to September 2023 and 330 valid answers were collected. The research presents the results obtained after the quantitative evaluation of the data received following the participation of students in the market research carried out within the Politehnica

University of Timisoara. The main results show that students do not have solid knowledge about slow fashion and the importance of this concept for environmental sustainability. Some courses taken on the concept of sustainability were observed to represent an important step in improving the level of knowledge. For the current research, market research was used by applying a questionnaire. The respondents are students of the Politehnica University of Timisoara and follow sustainability courses. The results obtained were analysed using SPSS.

4. RESULTS

4.1 Students' perception of shopping & clothes

The first objective of this study is to get a deeper understanding of students' perceptions and involvement in shopping and apparel. Through an exploration of the students' perspectives, our objective is to get significant insights into the influence of fashion and shopping on their daily existence.

Given the issue of garments' relevance, the data show a variety of viewpoints. Clothing was considered important by 36.7% of the respondents, which shows that it is a major topic in their daily lives. A large percentage of respondents (33.3%) said clothes are very important, suggesting that they shape their identity or their daily activities. The remaining statistics indicate that 26.7% of respondents see garments neutrally. On the contrary, 3.3% believe clothing is irrelevant (Table 1).

Table 1

How important is clothing to you? (1=not at all, 5=very important)

		Frequency	Percent
Valid	2	2	3.3
	3	16	26.7
	4	22	36.7
	5	20	33.3
	Total	60	100.0

We wanted to know how participants felt about garment material quality. Most people (96.6%) think the makeup of their clothing is important. The high percentage shows that, for most participants, material quality is an important element in their clothing choices. It was only 1.7% of the sample who thought material quality was irrelevant (**Error! Not a valid bookmark self-reference.**).

Table 2

How important is the quality of the materials from which clothing items are made? (1=not at all, 5=very important)

		Frequency	Percent
Valid	3	1	1.7
	4	29	48.3
	5	29	48.3
Missing		1	1.7
Total		60	100

Moving on, we will explore how apparel shoppers see pricing. Many participants (91.7%) reported that price is a significant driver in clothing evaluation, suggesting that price may be an important factor in clothing choosing. The remaining 8.3% imply a group that does not prioritise pricing in clothes choosing (Table 3).

Table 3

How important is the price of clothing items? (1=not at all, 5=very important)

		Frequency	Percent
Valid	2	2	3.3
	3	3	5.0
	4	28	46.7
	5	27	45.0
	Total	60	100.0

A linear regression model was used for a simple regression analysis. The importance of clothes was negatively correlated with age. This study suggests that as people age, they value clothing less. Changing our core assumptions changes our reactions. Further studies might examine the values that people adopt as they mature (Table 4).

Table 4
Importance of regression analysis of clothing and age

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.903	0.527		7.405	0.000
	Clothing importance	-0.409	0.129	-0.385	-3.175	0.002

4.2 Purchase behavior of the students

The second research objective focusses on examining the purchase behaviour of students. The goal is to gain insight into how students make purchasing decisions, what factors influence their choices, and their consumption patterns. Understanding the purchase behavior of students provides valuable information for both academia and industry, aiding in the development of strategies and policies tailored to the preferences and needs of this specific demographic.

The fact that 70% of the participants refreshed their clothing seasonally suggests a strong link to seasonal fashion trends. This is typical of the seasonal wardrobe change, as warmer or cooler clothes are added or eliminated. 18.3% of respondents who said they renew their wardrobe weekly may be more interested in fashion or clothing. The 11.7% of respondents who change their clothes every few weeks are a small but important group. This group may include frequent shoppers who like to research and following fashion trends. This group may also include those who love wardrobe diversity and frequently change attire.

A significant proportion of participants (60%) indicated a preference for frequenting fast fashion retailers. This finding suggests that a considerable segment of customers perceives fast fashion as valuable and has a strong dedication to making repeated trips. In contrast, a mere 16.7% of the participants express infrequent patronage of fast fashion retailers. These individuals may perhaps belong to a demographic that does not perceive quick fashion retailers as valuable and instead, favour high-end alternatives (Table 5).

Table 5
How often to buy clothes from fast fashion stores? (1 = never, 5 = always)

		Frequency	Percent	Cumulative Percent
Valid	1	2	3.3	3.3
	2	8	13.3	16.7
	3	14	23.3	40.0
	4	27	45.0	85.0
	5	9	15.0	100.0
	Total	60	100.0	

In the following investigation, we examine student luxury store purchases. The findings shed light on luxury retailer purchase habits. Understanding these trends is essential for assessing luxury fashion retail's market influence and how buyers view and interact with premium goods. Many participants (41.7%) said they occasionally buy clothes from high-end retailers. This shows that the person does not value high-end luxury stores or that the pricing of premium products affects their decision-making. Furthermore, 36.7% reported infrequent luxury clothes, while 21.7% reported regular use (Table 6).

Our next goal was to understand how often students buy fast fashion in stores vs. online. Given the above, the mean of in-store shopping is higher than online shopping. Respondents tend to prefer to buy in-store. This suggests that students like to test on clothes before buying (Table 7).

Table 6
How often to buy clothes from luxury stores? (1 = never, 5 = always)

		Frequency	Percent	Cumulative Percent
Valid	1	7	11.7	11.7
	2	15	25.0	36.7
	3	25	41.7	78.3
	4	10	16.7	95.0
	5	3	5.0	100.0
	Total	60	100.0	

Table 7
In-store vs. online fast fashion shopping

	N	Minimum	Maximum	Mean
How often do you shop online for fast fashion brands?	60	1	5	2.52
How often do you shop in the store for fast fashion brands?	60	1	5	3.45

To dig deeper, we investigated whether students make their own clothes. According to the research, more than half of the participants did not want to make their own clothes. However, a third were interested in investigating such pursuits, while the rest of the participants wanted to make their own clothes.

In addition, impulsive buying is common in the garment industry.

Subsequently, we sought to see if there was a statistically significant correlation between student wardrobe change frequency and online and in-store shopping. We found a statistically significant positive correlation between "Wardrobe refresh" and in-store purchase frequency. The following information was obtained: Students who often change outfits are more likely to attend brick-and-mortar stores. However, a weak connection was found between the dependent variable and internet retailers. This suggests that wardrobe updates do not affect Internet shopping behavior (Table 8).

Table 8
Regression analysis in store fast fashion and wardrobe refresh

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.657	0.343		1.917	0.060
	How often do you buy fast fashion branda in-store? (1 = never, 5 = always)	0.220	0.096	0.288	2.288	0.026

Moving on, we wanted to make the same analysis as above, but using as the dependent variable the perceived importance of clothing. We found a strong statistically positive relationship between the dependent variable and the constant in-store shopping frequency. In other words, students who place great emphasis on the importance of clothing tend to visit offline fast fashion stores more often (Table 9).

Table 9
Regression analysis in store fast fashion and importance of clothing

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.870	0.417		6.881	0.000
	How often do you buy fast fashion brand in-store? (1 = never, 5 = always)	0.328	0.117	0.345	2.800	0.007

To further understand the behavior of students, we wanted to make the same analysis, but regarding luxury stores. We found that there is a strong positive correlation between perceived importance of clothing and the frequency of purchases from luxury stores. Students that put great importance on clothes tend to prefer to buy from luxury stores (Table 10).

Table 10
Regression Analysis in store fast fashion and Importance of clothing

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.105	0.302		10.265	0.000
	How often do you buy clothes from luxury stores?	0.322	0.102	0.382	3.151	0.003

4.3 Students' perception regarding sustainability in fashion industry

The third goal is to examine the sustainability perspectives of students in the fashion industry. This goal is to investigate how young people, especially students, see and value sustainability in fashion. With increasing environmental and social concerns, the fashion industry is prioritising sustainability.

We intended to test students' understanding of sustainability in the fashion industry to continue our research. 76.7% of the respondents mentioned environmental protection, waste management, and resource consumption in the fashion industry. Other students (23.3%) said they had never seen this information.

Moving on, we wanted to know what students considered sustainable apparel. Choose from organic biodegradable textiles, repurposed clothing, or classic items. Material sustainability is how 60% of our questioners understand sustainability. The most trusted ecological apparel labels are organic or biodegradable. Next, recycled clothing, then timeless.

Next, we sought to study how clothing mass production affects students. Most of students believe garment manufacture harms the environment. Only 3.3% think mass-producing garments has a minimal environmental impact, while 23.3% are indifferent (Table 11).

Table 11
Do you agree that mass production of clothing has a negative impact on the environment? (1=Strongly disagree, 5=Strongly Agree)

		Frequency	Percent	Cumulative Percent
Valid	1	1	1.7	1.7
	2	1	1.7	3.3
	3	14	23.3	26.7
	4	22	36.7	63.3
	5	22	36.7	100.0
	Total	60	100.0	

The results show that 53.3% of the respondents avoid second-hand and vintage stores. Only 13.3% of the participants frequented such businesses (Table 12).

Table 12
Do you buy clothes from vintage or second-hand stores? (1 = very rare, 5 = very often)

		Frequency	Percent	Cumulative Percent
Valid	1	19	31.7	31.7
	2	13	21.7	53.3
	3	20	33.3	86.7
	4	5	8.3	95.0
	5	3	5.0	100.0
	Total	60	100.0	

According to the results, students prefer outlets. These businesses are known to sell premium goods at lower prices. Ecology benefits if a business sells its clothes to discount stores instead of destroying them. Only 6.7% never shop in outlet stores (Table 13).

Table 13
Do you buy clothes in outlet stores? (1=Never, 2=Sometimes, 3=Always)

		Frequency	Percent	Cumulative Percent
Valid	1	4	6.7	6.7
	2	27	45.0	51.7
	3	29	48.3	100.0
	Total	60	100.0	

Clothes reach their "end of life" when they are no longer functional or worn. This usually happens when clothes are too worn, torn, or out of style to be useful. Clothing can be discarded, recycled, recycled, or reused based on sustainability and environmental concerns. Clothes must be properly disposed of and recycled to minimise the environmental effect. Having said that, we wanted to know how students dispose of their clothes.

Next, a third indicated that they have not but would like to try it, and only a small number sell it often.

Moreover, we then asked the students if they had considered donating their clothing. Donating clothes has long-term societal advantages. Most respondents considered donating their unused clothes. Additionally, we checked how students dispose of old garments. A quarter of the respondents said they threw them away, while 75% gave them to collection facilities. Moving on, we wanted to analyse whether the perceived negative impact of mass clothing production influences whether students buy from different stores.

Table 14
Regression analysis outlet stores and environmental concern.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.472	0.431		5.729	0.000
	Do you buy clothes in outlets stores? (1=Never, 2=Sometimes, 3=Always)	0.653	0.173	0.444	3.775	0.000

The regression analysis showed a high positive connection between the constant and the dependent variable. People who are aware of the negative effects of clothing manufacturing favour outlet outlets. Outlet stores are generally associated with eco-friendly purchasing. The dependent variable was not strongly correlated with purchases from the SH or vintage store (Table 14).

In the end, we wanted to see how age influences the purchase decision in different stores. The only significant relevant correlation was found between age and outlet stores, and it has been negative. In other words, the older the respondent is, the less likely he is to buy from the outlet stores. Outlet stores often offer luxury brands, so it can correlate with a decrease in interest in luxury (Table 15).

Table 15
Regression analysis of outlet stores and age.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.408	0.461		7.400	0.000
	Do you buy clothes in outlets? (1=Never, 2=Sometimes, 3=Always)	-0.472	0.185	-0.318	-2.557	0.013

5. DISCUSSION AND CONCLUSIONS

Our investigation reveals students' perceptions, motivations, and attitudes toward the fashion industry. Clarifies their sustainability views of the apparel industry. It also reveals techniques and opportunities for corporations to sell to students that prioritise sustainability while buying new clothes. In conclusion, we concluded: There is a considerable incentive to buy apparel offline rather than online. This survey indicated that most students consider clothing prices. However, students want to make sure their clothing fits before purchasing. Compared to online buying, in-store shopping reduces risk. Online shopping could be made more attractive by offering free delivery and returns. Because online retailers have a less environmental impact than traditional businesses, online buying can be more sustainable. We also found that some buyers want to make clothes.

Companies can sell repair kits such as denim patches to provide competitive advantages and encourage sustainable behaviour. We propose manual sewing kits and online DIY lessons on the company's website for consumers who want to make their own outfits and participate in sustainable activities. We found that this method develops a feeling of identity for clothing, which is the key driver when respondents were asked what they think of when they hear the term 'clothing'. We also observed that students identify sustainable apparel with organic or biodegradable labelling. Companies that represent themselves as sustainable fashion should consider the environmental impact of their textiles. We advocate reducing product environmental footprints from the design phase. Life cycle assessment (LCA) is a solid starting point for sustainable product design. We also found a dearth of information about the benefits of shopping in SH or antique stores. Fast fashion retailers were preferred by 86.7% of respondents. The findings indicate a major obstacle to sustainable fashion. Future research should examine why these options are unattractive. The results demonstrate interest in selling unused clothing. We suggest that people participate in such practices since it benefits the environment by reducing the demand for new garments. If customers will not sell their clothes, they should use collecting centres. These are usually more sustainable than tossing away garments. It has a positive environmental impact, produces jobs, and generates income. Further research should examine how SH or antique stores may attract more customers, as they are greener options.

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GRAPHICAL METHOD FOR OPTIMIZING THE MACHINERY LAYOUT

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***Abstract**. The correct implementation of a material processing process is conditioned by the optimal organization of the workplaces, by the promptness of the means of transport, factors that are influenced by the way in which the machines are located within each production department. The achievement of an machinery layout plan is required if a new production capacity is developed, but an equipment re-layout may also be necessary if changes are made in the technological process, if the technological operations are not efficient or if new products will be introduced into manufacturing. One of the most used method for obtaining the machinery layout plan is the method of the systematic analyse of the space. The process of the machinery layout includes several stages, such as: building a matrix that identifies the circuit of materials from one area to another, determining the space required for each technological department, establishing the initial draft of the equipment layout and identifying the layout that leads to optimal results, and finally, obtaining the detailed layout based on the optimal solution established in the previous phase. The paper presents a graphical method for obtaining the machinery layout, a method that offers more benefits. One of the advantages is the fact that the method can provide dimensional variants of production departments and the possibility of adjusting them until a good dimensional variant is achieved. An analysis of the machinery layout can be done by checking the distances between the machines, between the machines and the walls of the building, etc. The lengths of the material movement routes along the technological flow can also be quickly calculated. There is the ability to quickly change the locations of the machines, to add new equipment or to add new building elements (walls, doors). The final variant obtained as a result of the optimization is exact, eliminating the errors that could have appeared if a classic method of solving the problem of machinery layout had been used.*

***Keywords:** machinery layout, systematic analyse of the space, CAD, optimization.*

1. INTRODUCTION

An appropriate location of the machines must ensure the integration of the system elements, the efficient use of the machines and the available space, the development of the productive system, by providing some spare spaces for further expansions, flexibility in the location of the machines, the elasticity of the layout when new products are assimilated in manufacturing or when the manufacturing process is improved. Also, an efficient location requires dividing the space into orderly work premises, an optimal density of the location and a placement of the machines in accordance with the development of the manufacturing process. For each activity, minimum spaces for location, maneuvering, storage, and movement are required, without neglecting the convenience of the arrangement and protection at the workplace [1,2,3,4].

The placement of the machines is carried out through a cyclical systemic approach that includes several phases that are represented in figure 1. The re-placement of the machines may be necessary if the technological operations are inefficient, if changes are made in the technological process or if new products are introduced into the manufacturing [1].

The correct placement of machines within a production section leads to an increase in the number of executed products and their quality so that the investment for the flexibility of productive activities can be supported [1,2,3]. The designers have in mind the achievement of a balance between the density of the location of the machines and aspects related to cost, operating capacity and safety at the workplace [5,6].

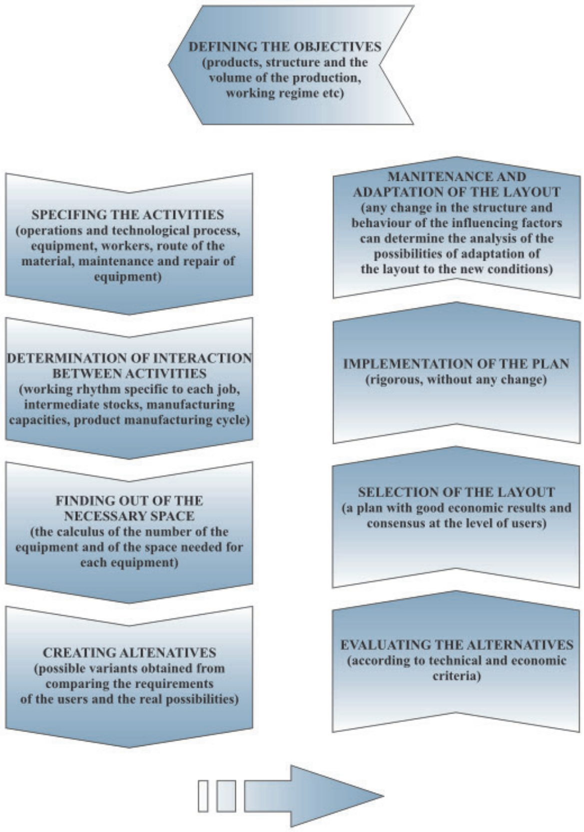

Figure 1. The cyclical process of the machines layout

Specialists concerned with layout design identified the importance of the flow of materials in the production department and sought to find and develop different computer algorithms to optimize it [7]. Also, in order to increase the production capacity, the design specialists used the method of systematic analysis of the layout and came to the conclusion that the costs related to the material handling operations can be reduced by approximately 11% compared to the initial variants [8].

In order to achieve an efficient location of the machines within the production units, specialized programs can be used [9,10], which uses the data related to the building, machines or equipment to achieve their location in an efficient way. Computer-aided graphics programs use classic drawing commands and tools. With their help, an analysis of the efficiency of the material flow can be made. The programs can be loaded with libraries of 2D digital models of factories and their modules that can help to optimize the location in the plan. Also, the drawings made in the plan can be transformed into 3D models.

2. EXPERIMENTAL PART

The specialized works present three types of placements for production spaces, namely placements on fixed stations, placements on processes and placements on products [1,2,3,11]. Locations at fixed stations are specific to production processes where the movement of materials, semi-finished products and sub-assemblies takes place towards a fixed place where they are processed and assembled to create the finished product. Locations on processes are characterized by the fact that the machines that perform the same type of transformation are placed in groups, and the homogeneous groups are arranged in a logical sequence that characterizes the majority of the production carried out. This type of location is specific to discontinuous flow production processes that produce a large range of products in small quantities. In the case of locations on production lines, the machines are arranged in the order of the technological process so that the semi-finished products move from one operation to another on successively placed machines forming the manufacturing line. Placement on production lines is used by enterprises with continuous flow manufacturing processes, which make few products but in very large quantities, mass production or large series [1,2].

The systematic arrangement of the space is applied in the case of the location of new factories and in the case of changes made within enterprises or laboratories, in the space of existing or new buildings. This placement method consists of a number of procedures and a set of conventions [3, 4].

The main stages of the location involve the construction of a matrix in which the circuit of materials from one area to another is identified, the determination of the space required for each technological department, the establishment of the initial drawing of the machines location for which the minimum costs must be calculated and the identification of the layouts that lead to optimal results , by locating the work areas where a large amount of semi-finished products are transported close to each other, and finally, obtaining the detailed location based on the optimal solution established in the previous phase.

The arrangement of the space is carried out in four stages. First of all, it is established which is the surface that represents the support of the project, taking into account whether the new location will be made on a surface that will be made available for this purpose or in a newly acquired building. In the second stage, a general location plan is developed, establishing the diagrams of the general technological flow. The dimensions, relationships and configurations of each compartment, activities or areas are established. In the third stage, the detailed plan is developed through which each piece of equipment is placed, and in the fourth stage, the implementation plan is made, respectively the installation plan, its physical realization and the necessary adaptations. It is indicated that in order to obtain good results, the sequences of these stages should partially overlap [3, 4].

Before solving the second and third steps, the basic input data must be identified, especially those regarding the product or material (e.g. yarn characteristics), the volume or quantity of each product, the technological process (operations in the flow technological), the sequence of operations and the related machines, the services and auxiliary activities that participate in the realization of the production, the duration of the operations and norms.

3. RESULTS AND DISCUSSION

3.1. Determining the areas occupied by machines and their related storage spaces

Table 1 shows the machines to be placed, as well as the surfaces occupied by them and the storage spaces. The machines are grouped by sections because they work in environments with different temperature and humidity, as well as in environments with releases of dust, fluff or impurities in different concentrations. The machines are numbered in the order in which they are used within the technological flow. For the case study used to exemplify the method, the machines necessary to obtain a technical yarn obtained from long line flax, processed through a technological process specific to long fibers, with a linear density of 80 Tex and chemically untreated, were taken into consideration.

Table 1
The total area of machines and storage spaces

Sections	Machines	Number of machines	The area occupied by a machine and the storage space, m^2	Total area occupied by machines and storage spaces, m^2
1	M 1	4	57.0	227.8
2	M 2	4	13.0	51.8
	M 3	2	31.3	62.6
	M 4	2	31.5	63.0
	M 5	2	36.3	72.6
	M 6	3	43.7	131.2
	M 7	3	40.4	121.1
	M 8	4	60.5	241.9
3	M 9	13	23.2	301.8
4	M 10	3	19.3	58.0
5	M 11	1	37.2	37.2

M1 - Hackling machine, FA101; M2 - Sliver forming machine, FA201; M3 - Doubler, FA280; M4 - Drawing frame I, FA281; M5 - Drawing frame II, FA282; M6 - Drawing frame III, FA283; M7 - Drawing frame IV, FA284; M8 - Roving frame, FA401 B; M9 - Spinning frame, FA506; M10 - Dryer, Impianti tessili ALEA, M12 - Winding machine

3.2. Realization of the placement of machines within the section that includes the largest number of machines

The proposed graphic method assumes that first a network of resistance pillars is graphically represented, a network that occupies an area as close as possible to the value resulting from the calculations based on the data in Table 1. The distances between two successive resistance pillars, in the horizontal direction and in the vertical direction, are established after a careful analysis of the dimensions of the machines to be placed in the production sections.

The machine with the longest length is the one marked with M9, the value of its length being 13.7 m. Taking into account the fact that on both side parts of the machine there must be sufficient space for servicing, for repairs, for the movement of people and for transport, the minimum distance between two resistance pillars between which the machine will be positioned is approximately 19 m. Therefore, the standardized distance immediately above this value is 21 m. In other words, one of the dimensions of the network cell of pillars that will be adopted has the value of 21 m. A cell of the pillar network is delimited by four pillars that are placed in the four corners of the rectangle with the minimum surface within the network, respectively two successive pillars along the length direction and two successive pillars in the width direction. In order to determine the other size, it is necessary to analyze the space occupied by the machines, the storage areas and the space allocated for the traffic lanes for the section with the largest number of machines, respectively Section 2.

If the machines are placed one after the other and are grouped in such a way that they fit in the width between two resistance pillars, then, as can be seen in Figure 2, the length of Section 2 will be 120 m. Because the distance between two pillars of resistance in this direction must be a multiple of 3, the minimum value being 6 m and the maximum value being 21 m, it follows that the distances between the resistance pillars that can be adopted in this direction are 6, 12, 15 or 21 m. The cells of 6 x 21 m and those of 21 x21 m are not recommended in practice due to the value of the ratio between width and length that does not fall within the optimal range (0.5 - 0.75). Therefore, the distance between the resistance pillars that can be adopted can be 12 or 15 m. If the value of 12 m is adopted, it follows that for this location variant, 10 network cells (network units) with a length of 12 m and a width of 21 m will be needed for Section 2. Since the ratio between the width and the length of section 2 in this case will be 0.175, respectively a value that is far outside the recommended optimal range, this option is abandoned and another arrangement of the cells of the column network is chosen, so that the dimensions of the Section 2 to be optimal.

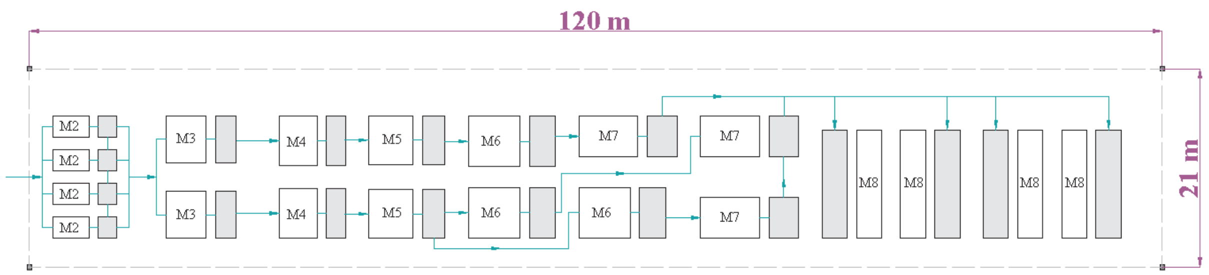

Figure 2. Placement of machines within Section 2 - option 1
▯ - storage space; ■ - pillar of resistance; → - the route of the material within the technological flow

In the case of the second location option, for an optimal ratio between the width of the section and its length, the 10 grid cells that are necessary for the framing of the machines in Section 2, will be arranged in two rows with 5 cells each, as can be seen in Figure 3.

After representing the network of optimal pillar, the machines and the related storage spaces are drawn within the section that has the most machines, and which, possibly, are different from each other from a constructive point of view. Their positioning is carried out in the order of the technological flow, on the surface related to the respective production section, considering that the transport of the materials must be done as quickly and easily as possible.

The computer-aided graphics program used to create the drawing, respectively Autodesk® AutoCAD®, allows the calculation of the section's surface area, as well as the area occupied by the machines together with the related storage spaces. Thus, the correctness of the graphic representation can be checked, comparing the values calculated by the computer-aided graphics program with the input values, values based on which the graphic representation is made.

After representing the machines, the material route is drawn within the technological flow and the route lengths are calculated for each individual option.

In both previously presented variants, the surfaces occupied by machines, storage spaces and areas for the circulation of personnel and materials are the same. The length of the material path from one machine to another is greater by 98.4 m in the 2nd variant compared to the route that the material must follow in the 1st variant. However, the second variant offers a better overall visibility of the section , with the ability to act more quickly in the event of a breakdown or interruption in the operation of a machine. Also, in the case of the second option, the areas for circulation are placed to a greater extent between the machines, respectively at a certain distance from the main passage, i.e. from the area that is more congested and that can cause material flow slowdowns. Therefore, this option will be adopted for the case study presented in the paper.

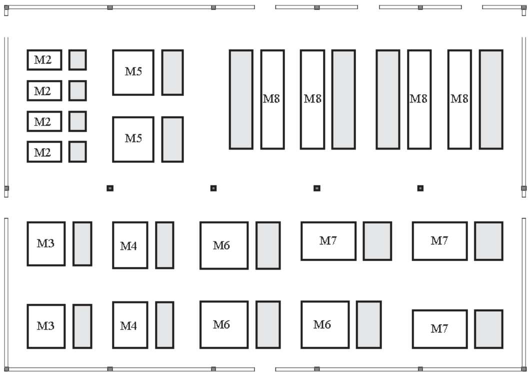

Figure 3. Placement of machines within Section 2 - option 2

3.3. Realization of the placement of machines within the other sections

The placement of the machines from the other sections is carried out so that the material route along the technological flow is continuous, without turns and without intersections of the material flow. The location of the machines for all 5 sections can be seen in Figure 4.

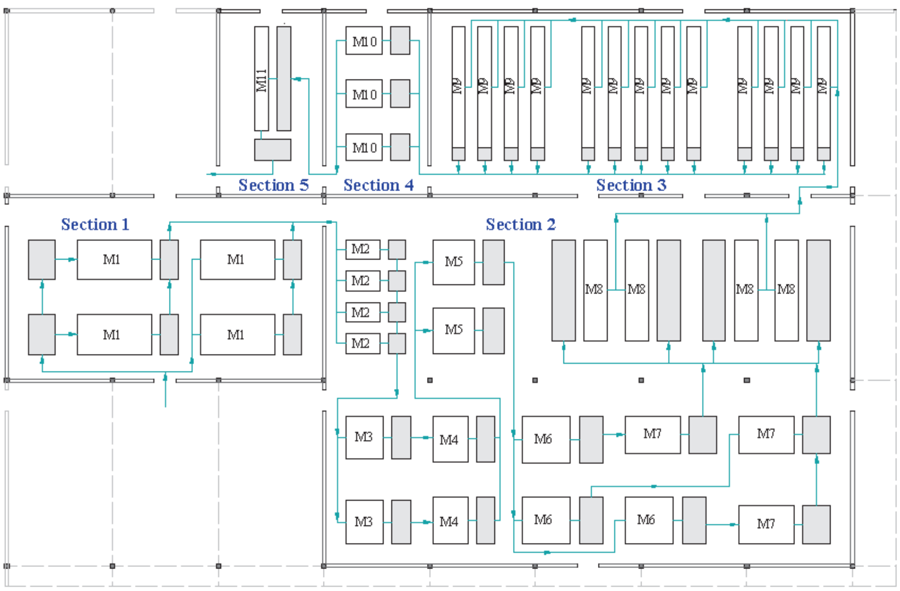

Figure 4. The location of the machines within the five sections

Inside the cells of the network of pillars located around the production sections, the sections for servicing the production are located, such as: a warehouse for raw materials, a warehouse for waste, a warehouse for auxiliary products, a section for packaging technical threads, a warehouse for final products, a laboratory for determining the physico-mechanical characteristics of the raw material, a laboratory for determining the physico-mechanical characteristics of materials at various stages of intermediate manufacturing, a laboratory for determining the physico-mechanical characteristics of yarns, an electrical workshop, a warehouse for devices used for the transport of materials, a compartment for fire protection, a workshop for welding, a workshop for carpentry, a mechanical workshop, changing rooms for working personnel, offices for foremen, a compartment for the air conditioning system.

The previously presented stages lead to the realization of a sketch of the location of the machines within the sections, as well as an adequate arrangement of the annexed departments, a sketch based on which, later, the actual location and the detailed plan will be made, after a systematic analysis carried out by specialists from various fields, textile engineers, construction engineers, architects, installation engineers, electrical engineers and others.

4. CONCLUSIONS

Using the computer-aided graphics programs, changing the positions of the machines within the section can be done easily. Precise calculations can be made related to the area occupied by the machines, the dimensions of the storage spaces can be easily changed, and the areas occupied by them can be calculated, for each machine in part or in total. Also, the dimensions of the areas allocated to the transport of materials or to the circulation of service personnel can be quickly calculated and modified.

To create the detailed site plan, specialized programs and applications can be used, such as those mentioned in the introductory part, but they need an initial database, data that only a textile engineer or an engineer specialized in industrial design can provide in an appropriate and suggestive way. There are situations and constraints that only the textile engineer can know and that can decisively influence the location of the machines. Therefore, before creating the detailed location plan, it is necessary to create a preliminary location sketch, a sketch that takes into account all the rules and constraints generated by the specific operation and the particular processing mode of each machine. Using only machine dimensions and storage spaces as input data will not lead to a correct site plan.

This graphic method presented in the paper can be useful to engineers and managers who will have to make a sketch or a drawing of the location of the machines within the production sections of a textile company.

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LABOR FLEXIBILITY: A FRAMEWORK OF ANALYSIS

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***Abstract**. Flexibility is the ability of a system to adapt to different environments and situations to cope with changes in the policies and rules related to the business environment. Labor flexibility is represented by a set of measures that act on labor rights, proposing a model of harmony/balance between employers and workers (employees). Considered an integral part of the modernization of the labor market, the term of labor flexibility appears mainly in crisis. With the outbreak of the COVID-19 pandemic, the great challenges faced by organizations to maintain functionality, maintain employees, and achieve the proposed objectives, together with the huge pressure on the employees who were facing the scenario of being out of a job or without income, led to finding the most suitable forms of work to overcome those challenged times. Before this crisis, organizations knew about the existence of certain working methods but viewed them as too modern, and difficult to implement, and not regulated by law in most European states. Labor flexibility became a necessity during the pandemic, currently being privileged as normality for both employers and employees, being regulated by law in most countries. The purpose of this paper is twofold: to offer an overview of labor flexibility and to explore and identify how the forms of labor flexibility have been adopted, respectively adapted, by various European companies to face the challenges encountered as a result of the COVID-19 pandemic period. The exploratory research will be approached to carry out a comparative analysis on the forms of labor flexibility most used at the European level, emphasizing those whose use during the crisis was successfully embraced at the company level, therefore being considered as examples of good practices.*

***Keywords:** Covid-19 pandemic, hybrid work, labor flexibility, telework.*

1. INTRODUCTION

The notion of flexibility emerged from the necessity to adapt to the needs and changes in the labor market but also in people's daily lives. Work flexibility has been and is a method used to overcome labor market problems such as those caused by low birth rates, an aging population, job reductions, and rising unemployment, especially among young people, but also a form of maintaining competitiveness in a constantly changing environment. According to the literature, work flexibility has arisen mainly in crisis, and its practice is justified by the fact that, in this crisis, it prevents workers from losing their jobs and companies from reducing their production.

After World War II, the COVID-19 outbreak produced the most severe social and economic recession. All the aggressive restrictions imposed worldwide on isolation and social distancing have led to significant damage on all levels, which will be felt for a long time. All organizations, whether private or state-owned, from the smallest to the largest, have suffered significant damage and had to find the best solutions and policies to survive.

Pre-COVID-19 financial crises, such as the one caused in the 2000s in the US by bird flu that led to lockdowns, led to increased interest in flexible forms of work. Work flexibility, viewed as work arrangements and models, allows employees and employers to shape and adjust work schedules to the demands of life and the needs of the economic market. The concept helps organizations in a constantly changing economic environment to flexibly provide the human resources necessary to operate in order to achieve their objectives [1-3]. It is considered an integral part of the modernization of the labor market and seen as an effective solution to today's labor market problems.

The implementation stage of work flexibility differs from country to country, depending on the degree of development, as the flexibility of forms of employment, but especially of the organization of working time, is a socio-economic innovation of particular importance with both macroeconomic and microeconomic impact. Nickell considers that, at the macroeconomic level, work flexibility must be implemented considering three main aspects: employee protection, labor standards, and labor policy. [4].

Forms of labor flexibility began to be used as early as the 70s. In 1984, Atkinson argued in his research that companies view flexibility from three points of view: a) functional, which refers to the possibility of employers to move and adapt to other compartments of the organization and to retrain in work; b) numerical, refers to the possibility to hire or dismiss staff so that the organization permanently has the optimal number of employees and c) financial flexibility, refers to differentiated remuneration based on employee evaluation [5-6].

Through more recent research, specialists in the field have concluded that work flexibility must be analyzed from the perspective of four aspects, namely spatial, temporal, functional, and numerical, aspects that have no influence on the achievement of employees' work tasks or on individual objectives to be achieved [7-8]. In this sense, spatial flexibility refers to the place where employees work, temporal flexibility refers to how working time is organized, functional flexibility refers to the flexibility of an employee to perform various tasks in different compartments, while numerical flexibility refers to supplementing the need for personnel for a determined period when needed.

With the outbreak of the COVID-19 pandemic, the challenges to which organizations have been subject to maintain functionality, maintain employees, and achieve the proposed objectives, together with the hard pressure on employees who saw themselves in the position of being without a job or income, have led to finding the most suitable forms of work to overcome this difficult period. Before the crisis organizations knew about the existence of flexible working modes, but most regarded them as modern methods hard to implement and not regulated legislatively in most states. During the pandemic, work flexibility became a necessity, currently being considered a normality by both employers and employees, the forms of work flexibility being regulated by laws in all countries. Hence, the necessity/ importance to explore and identify how the forms of labor flexibility have been adopted, respectively adapted, by various European companies to face the challenges encountered as a result of the COVID-19 pandemic.

2. WORKFORCE FLEXIBILITY: PRE-PANDEMIC VS. DURING PANDEMIC APPROACH

2.1. Methodological approach

The methodological approach in this case consisted of conducting a comprehensive literature review to achieve the set objective of the paper. A comprehensive literature review is a valuable component of any research project, as it provides a great knowledge base for one's study and helps the researcher to understand the existing research landscape. This approach demonstrates a systematic and rigorous process for gathering and analysing relevant literature to support the research objective.

In this context, the authors started with the investigation of various internationally recognized databases (Elsevier, Emerald, Google Scholar, ProQuest, Springer, so on) based on a few keywords of interest, such as ”labour flexibility” ”Covid-19 Pandemic” ”hybrid work” and ”telework”. Thus, it was possible to extract a consistent number of scientific articles, reports, and books dealing with the subject addressed.

After collecting the literature, the authors have analysed and synthesized the information. It involved categorizing the findings, identifying common themes or trends, and assessing the current state of knowledge in the field. Consequently, the exploratory research was approached by carrying out a comparative analysis on the forms of labor flexibility most used at the European level, emphasizing those whose use during the crisis was successfully embraced at the company level, therefore being considered as examples of good practices.

2.2. Workforce flexibility approach before COVID-19 pandemic

Since 1990, working conditions have begun to be researched at the European level, following the evolution of working conditions and the relationships between their different aspects in order to develop European policy on employment issues related to the quality of work. Among the topics covered by the research were the organization and duration of working time, work organization, and work-life balance.

The European Institute for Research, Education, Health and Security of Trade Union Organizations conducted, in 2009, complex research, and among the fundamental objectives proposed was the flexibility of the workforce from different countries of the EU at the level of economic agents [9]. According to the study, the measures taken by France were: the duration of the working week has been reduced to 35 hours without changing wages, applying the flexibility of shift work, as well as the increase in holiday periods, as a result of the decrease in the number of working hours, they implemented partial unemployment; supported and encouraged employees to participate in professional training programs; introduced flexible working time; provided monetary compensation to those who voluntarily left their jobs [8-9].

In Belgium, organisations suspended their activities by resorting to temporary unemployment. In this case, the state got involved by increasing the amounts related to temporary unemployment, decreasing VAT in construction, and investing in public infrastructure. In the Netherlands, domestic temporary employment agencies played an important role in dealing with the reallocation of the temporarily unemployed employees. Concomitantly, the forms of training and professional requalification for people who are temporarily unemployed have intensified. Temporary unemployment was granted for periods ranging from 6 to 24 weeks. As for Germany, the state used collective agreements and reduced working hours without using temporary unemployment. Longer holidays were granted, overtime no longer existed, and hours of inactivity left due to reduced working hours were used for vocational training [8].

Other states, as the case of more recently entered into the European Union, such as the Czech Republic, Bulgaria, Hungary, and Romania, with precarious legislation and limited financial resources, as well as the lack of flexible working schemes, registered redundancies, extension of leave periods, temporary cessation of organizations activity.

According to the afore mentioned study, during the financial crisis, the legislative measures adopted by Romania to make working conditions more flexible, especially part-time or fixed-term contracts, did not have the desired and favorable consequences, leading to precarious relations between employees and employers. In these circumstances, the weekly time allocated to work increased, and over half of the employees who worked in a temporary working regime had weekly working hours over 40 hours, while only a quarter of the employees who worked part-time respected the usual working week proportionally to the part-time work schedule [10]. Consequently, organizations have used resources only to survive, the fate and security of employees not being ensured, but there have also been a series of good practices that have been implemented with confidence in Romanian organizations to meet the effects of the economic crisis, but also of the economic and financial recession [8].

In 2017, before the outbreak of the COVID-19 pandemic, a Joint Report by the European Foundation for the Improvement of Living and Working Conditions (Eurofound) and the International Labour Organisation (ILO) was drawn up entitled ”Working anytime, anywhere: The effects on the world of work” [11] which endorsed the study of the influences of flexible working forms in 10 EU Member States, but also in 5 non-EU Member States.

The report highlighted the fact that, at that time, from state to state, sector to sector, or profession to profession, spatial flexibility varied between 2% and 40%. In the public sector, France, Norway, Switzerland, Estonia, Finland, Sweden, Belgium, Germany, and the Netherlands offered employees the choice of whether or not to use forms of flexible working, the main form used being teleworking [11]. According to the report, 2.8% of employees in the European Union aged between 15 and 74 used forms of work flexibility. The country with the highest level of home workers was the Netherlands, followed by Luxembourg and Finland, while Romania was at the bottom with only 0.3%.

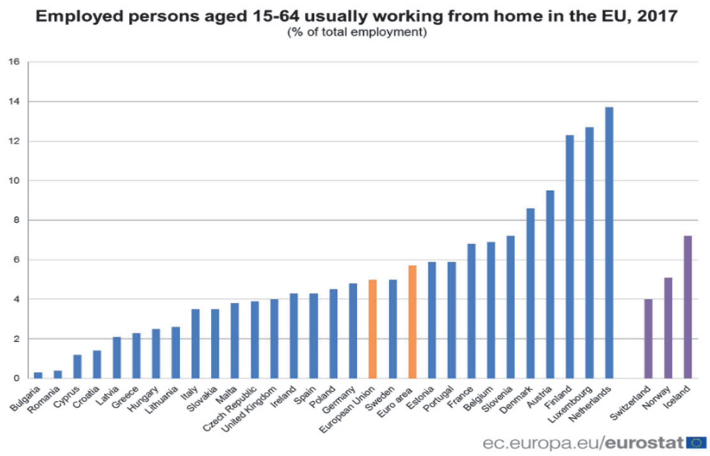

Figura 1. Employed persons aged 15-64 usually working from home in the EU, 2017 [11]

Also it could be noted that, in the Member States, the flexible forms of work have been used mainly in the fields of information technology, financial services, general services as well within the public sector. Finland found that the implementation of flexible working, especially teleworking, reduced carbon emissions by reducing travel to and from work [9], and staff eligible for flexible working were mostly senior staff with higher education.

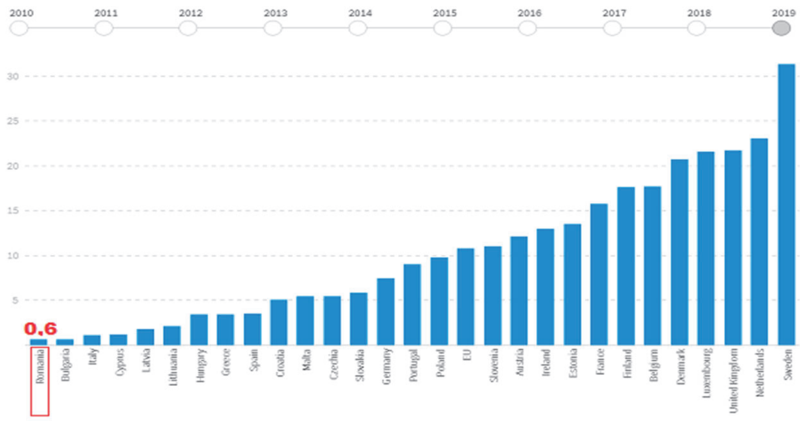

Figura 2. Employed persons who occasionally work from home, 2010-2019 [12]

The report's results also revealed that 61% of the total number of employees participating in the study have flexible start and end times of working hours. Rigid work schedules have gradually been replaced by trust-based work schedules, making employees more autonomous, and thus temporal flexibility has been established. Sweden, Norway, and Denmark were the countries offering the most flexible time arrangements, particularly to employees on permanent contracts [12]. In 2019, the countries that registered the lowest percentage of the total number of employees who worked sporadically from home were Italy, Bulgaria, and Romania, the latter ending the ranking in last place with a percentage of 0.6% of all employees.

2.3. Workforce flexibility approach during COVID-19 pandemic

During the COVID-19 pandemic, each state has tried to minimize social interaction, thereby reducing the risk of diseases. At the request of the World Health Organization (WHO), the governments of the EU member states considered the fight against infections a priority and adopted special laws in this regard, especially in 2020, when it was the peak of infestations and deaths. Among them, the European Union Regulation 2020/460 of the European Parliament and of the Council of 30 March 2020 amending Regulation (EU) no. 1.301/2013 and Regulation (EU) no. Regulation (EU) No 508/2014 regulates certain specific measures to mobilise investment in Member States' health systems and other sectors of their economies in response to the COVID-19 outbreak - Coronavirus Response Investment Initiative [12].

In the context of the epidemiological situation determined by the spread of the SARS-CoV-2 coronavirus, teleworking and working from home have suddenly become popular, being recommended by the authorities, both to maintain jobs and protect employees' incomes, as well as to mitigate employers' financial losses and accelerate the global economic recovery [13].

At the beginning of the pandemic, working from home or teleworking was not viewed with confidence by employers, as they believed they believed that employees would give more importance to family life, being at home, distracted from professional activities. Over time, however, it proved its efficiency, the productivity of employees increasing in the first phase due to the enthusiasm of employees to work from the comfort of home, but also due to gaining time allocated to travel to and from work, or time with informal discussions between colleagues, time gained for activities with family [14].

Although digital technologies, such as video calls and cloud file sharing, existed and functioned efficiently before the Pandemic, during the Pandemic, they created dependencies and have been definitively implemented in the vast majority of organizations, thus putting employee productivity and well-being first. Employee efficiency and productivity differed from one company to another, depending on the field of activity, being directly influenced by: a) their acute mental state by the lack of face-to-face interaction and isolation; b) digital fatigue that they have accumulated, some of them not being used to the digital environment, to the means of online communication; c) remote conflicts between employees who no longer had the strength or motivation to focus on what they had to do; d) how companies have invested in benefits and resources for them, resources to compensate for the lack of direct interaction and isolation [15-16].

At the European level, the European Foundation for the Improvement of Living and Working Conditions started a survey in April 2020 entitled ”Living, working and COVID-19”, which ran in five stages until April 2022 and aimed to find the best solutions for recovery from the pandemic crisis. It mainly examined the employment situation of those who responded to the survey, work-life balance, also issues related to teleworking and teleworking during the pandemic, the need for government support schemes, job quality and occupational safety, and health.

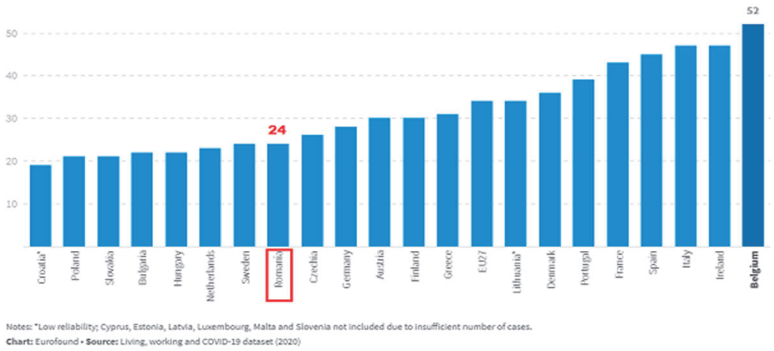

Figura 3. Employees working exclusively from home, by country (EU27), during the pandemic (%) [12]

According to this study, in Belgium, more than half of employees (52%) declared in July 2020 that they work exclusively from home, a share similar to that in Ireland (47%), Italy (47%), Spain (45%) and France (43%). While the European average was 34%, in Romania, 24%, all these percentages differ depending on the structure of the economy, the infrastructure, and the work culture.

Research/ statistics at the European level have shown that from year to year, the percentage of employees working from home constantly increases even after lifting the state of emergency. If in 2022, 49% of those surveyed worked from home imposed by the employer, in 2023, the percentage increased to 64% of those interviewed, 18% returning to the office one day a week. If we were to take into account employees' preferences, in 2022, only 49% would have wanted to telework from the comfort of home, while in 2023, the percentage increased to 71%, while only 1% of those surveyed wanted to work only in the office, after the old regime applied before the pandemic [17-18].

In Romania, the context created by the COVID-19 pandemic led to an increase in the percentage of employees working from home or applying teleworking to 24% in July 2020. Given the above-mentioned aspects, researchers consider that some factors, specific to the internal and external environment, can have an impact on the conduct of teleworking in the pandemic context and, moreover, can generate changes in the behavior of Romanian managers [13]. The study conducted for 2020 among organizations by Cornea highlighted that in the case of 30% of companies, employee productivity increased, while 44% of surveyed units did not notice changes in worker productivity [19].

3. RESULTS AND DISCUSSION

Before the COVID-19 pandemic, in many European countries, there were strong labor laws and regulations that favored job security. Employment protection legislation often made it difficult for employers to lay off workers, and many workers had long-term contracts with job security. Despite job security, some European countries have already adopted various models of workforce flexibility. These included part-time work, temporary contracts, and fixed-term contracts. However, such arrangements were typically more regulated than in other parts of the world. However, remote work was not as common in Europe before the pandemic, many jobs required a physical presence in the workplace, and remote work was generally not a widespread practice.

In response to the pandemic, many European governments introduced temporary measures to provide flexibility for both employers and employees. These measures included wage subsidies, furlough schemes, and simplified procedures for temporary layoffs. The pandemic forced a rapid shift to remote work in many sectors. This led to a significant increase in remote work and highlighted the potential for a more flexible approach to work in the future. At the same time, the pandemic brought about changing attitudes toward work. Both employers and employees began to realize the potential benefits of more flexible work arrangements, such as reduced commuting time, better work-life balance, and increased productivity for some roles. On the other side the pandemic's economic impact led to increased unemployment and reduced job security in some sectors, prompting a reevaluation of labor market flexibility.

According to the research undertaken, the fields with the highest rates of employees working from home were education, financial services, and public administration, and of those who worked from home during the crisis, 54% had worked remotely before, and 46% were new telecommuters. As for the age of first-time remote workers, young people (18–34 years old) accounted for the highest proportion at 49%, while older workers (over 50 years old) accounted for 45%, the difference between the two categories is not very large.

If in 2019, the pre-pandemic year, 31% of employed people in Sweden sometimes worked from home, this being the highest share in the EU, starting with March 2020, the extent of the changes produced by the installation of the pandemic period was amazing. Among the countries that experienced a real transition in terms of working conditions was Romania, where the evolution of telework has been insignificant in the last decade, occupying the last position of the EU ranking every year, based on the percentage of total workers, and it has risen from 0.1% of employees who worked from home from time to time, to only 0.6% in 2019. In 2020, the share jumped to 24% of the total, employees who worked and are working only remotely, which propelled Romania six positions in the EU27 ranking.

Making the working mode and time more flexible has proved to have many advantages among employees, especially at the organizational level, some of which listed in Table 1.

Table 1

Advantages and disadvantages of flexible working types and time [7, 8, 19-28]

At the level of	Advantages	Disadvantages
E M P L O Y E E S	Job satisfaction – being able to choose the place and time when they work makes them more efficient and happier; Productivity – they work where and when they feel most productive. A more balanced life. An optimal work-life balance. A better relationship with the employer. Eliminating the time allocated to going from home to the office and to come back home from the office. Possibility to supervise children. Reducing work-related stress. Effective use of working time. Reducing absenteeism from work. Taking responsibility for work’s final result. The possibility of continuing the studies. The possibility of having one more job.	Lack of social interaction can lead to lack of productivity for some, which in the long run leads to decreased motivation to work. Higher expenses with the arrangement of the workspace. Low concentration for those who live in small spaces and have children. Lack of movement from the comfort of home can lead to illness and social isolation. Difficulty creating barriers between personal and professional life. Unpaid overtime. Deficiencies in ensuring safety at work. Lower salary for part-time work. Lack of adequate space for the work done. Difficulties in disconnecting after work/ Utility expenses.

At the level of	Advantages	Disadvantages
O R G A N I Z A T I O N	Job satisfaction of workers – happy employees lead to an increase in profit and profitability of the organization. Better relationship with employees. Avoiding staff oversizing. Reducing delays and absenteeism. More efficient and better trained staff. Employee loyalty. Minimizing and avoiding staff reductions. Reducing fatigue at work. Decrease in expenses with the maintenance of premises. Avoiding overtime work costs. Attracting and retaining human resources. Reducing staff turnover on the same position. Decrease in the number of sick leave. Prolonged availability of some departments. Better assumption of responsibilities by employees, being directly responsible for the result of their work.	Diminishing organizational culture. Lack of coordination between employees and bosses; Lack of communication between employees and the poor information about events within the organization. Digitization and staff training expenses. Greater risks in ensuring the security of the information used. Difficulties in time management, and recruitment and selection of the employees. Poor recording of hours worked. Poor collective bargaining. Difficulty in solving emergencies. Difficulties in organizing meetings. Difficulties in vetting employees. Lack of sense of belonging to the collective. Loss of team spirit. Difficulties in correcting mistakes.
S O C I E T Y	Greater involvement of parents in the lives of children and family. Diminishing work-related morbidity. Reducing traffic jams at certain hours. Minimizing costs related to care services. It maintains competitiveness and economic growth in an ever-changing environment.	Development of social isolation syndrome, especially for employees who work exclusively at home or remotely. Affecting social dialogue.

4. CONCLUSIONS

In early March 2020, European leaders declared that life as we knew it was over, at least for a while, the employers being advised to telework immediately where possible and, in the case of "essential" occupations, to reorganize working arrangements to avoid diseases. Hence, during the COVID-19 pandemic, the use of flexible working arrangements, in particular working from home and teleworking, has helped ensure continued work, reduce the risk of illness, preserve jobs and protect employees' incomes, as well as mitigate employers' financial losses and accelerate the global economic recovery.

The pandemic and closure period was considered a period of the recession in the labour market; attempts were made as much as possible to reorient the carrying out of gainful activities, applying the basic rule - social distancing - imposing work outside the employer's premises, teleworking or working from home, forms of work rarely used among private organizations, and in public administration almost absent.

Before the crisis caused by COVID, the work schedule was organized mainly by the employer in rigid work schedules, which followed more the interests of the organization and less the interests of the employees, who respected the required hours of start and end of working periods, flexible forms of work rarely being used and only in specific fields of activity, and especially in times of crisis.

With the passing of the pandemic period, flexible forms of work continued to be used by a large part of organizations, especially in the private sector, in developed countries, and even in the public environment. Employees increasingly want to choose the strategy they carry out their work and prefer hybrid forms of work organization. Currently, hybrid work, whether it concerns working exclusively outside the employer's premises, partly on the employer's premises, on a compressed weekly schedule, or any other form of flexible work, is seen as the way to develop organizations, but also employees, to improve labor productivity, to mobilize workers to stay on the labor market, to advance in careers, to ensure a balance between work and family life, and all these being regulated legislatively throughout the European Union.

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REORIENTING THE ROLE OF TEACHERS AND TEACHING ACTIVITY DURING THE COVID-19 PANDEMIC PERIOD. A CASE STUDY ON AN AGRICULTURAL TECHNOLOGICAL HIGH SCHOOL FROM ROMANIA

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Abstract. *The Covid-19 pandemic has raised significant challenges for the education community around the world. In Romania, a particular challenge was the urgent switch from onsite to online teaching, without any prior training of teachers in this direction, nor the provision of adequate technical support from the very beginning. Online teaching and learning involve some pedagogical content knowledge, mainly related to designing and organizing better learning experiences and creating distinct learning environments, with the help of digital technologies. The aim of this paper is to analyze the reorientation of ways of teaching activity, the modification of perceived roles, and the changes brought about by online pre-university education. Hence, in order to identify how some pre-university teachers felt these sudden changes, research was undertaken in an Agricultural Technological high school in Romania. The focus was on the analysis of the way in which the didactic act was carried out during the online education period, compared to the post-online one (traditionally, with the integration of technology), with the identification of the difficulties encountered by the teachers and the reorientation of the educational act. The qualitative research consisted of conducting semi-structured interviews with teaching staff from the institution where the study was carried out. Although online teaching was a challenge for the entire pre-university education, in Romanian agricultural high schools, where pupils mostly come from disadvantaged backgrounds, social differences were amplified. The present research clearly showed that the Agricultural Technological High School faced online teaching with great difficulty, not being prepared for this situation in terms of resources. Of course, a high adaptability of the teachers was noted, who used their own resources and learned to use educational platforms and digital tools in record time to still manage to keep the teaching-learning process active.*

Keywords: *Covid-19 pandemic, digital technology, pre-university education, on-line education.*

1. INTRODUCTION

On March 16, 2020, a state of emergency was established in Romania because of the COVID-19 pandemic, which considerably limited the mobility of the population, imposed restrictions on land and air transport, quarantine measures for Romanian citizens coming from abroad, and so on. In terms of education, the entire onsite education system was closed down, situation that stretched over a period of one and a half years, in both pre-university and university education systems. During this time teachers and professors, pupils and students were forced to carry out the education process in entirely new and unknown circumstances for the majority of them: online teaching and learning.

The term "online learning" is widely used, but with a variety of meanings. For the purposes of this article, online learning refers to learning that is mediated by the Internet. It is more comprehensive than "networked learning". It is narrower than 'eLearning' and 'digital education', which include the full range of digital tools and resources, not just the internet, and a focus on developing digital skills. Furthermore, online learning lacks the built-in claim to enhancement that makes "technology-enhanced learning" (TEL) [1][2] a problematic phrase [3].

Worldwide, because of the COVID-19 pandemic, approximately 1.7 billion students got affected by school closures in 190 different countries in 2020 and 2021 [4]. The sudden shift to online teaching has been accompanied by many challenges. Almost all pedagogical approaches, content areas, lesson pacing, interaction patterns, and assessment methods were changed during the transition. This increased the burden on teachers who were asked to align digital educational content with their existing national curricula and at the same time respond to the academic, mental health, social and emotional needs of students [5]. Online teaching approaches have rarely been treated in the specialized literature because of the need for an effective combination of pedagogy, informational content and technology [6].

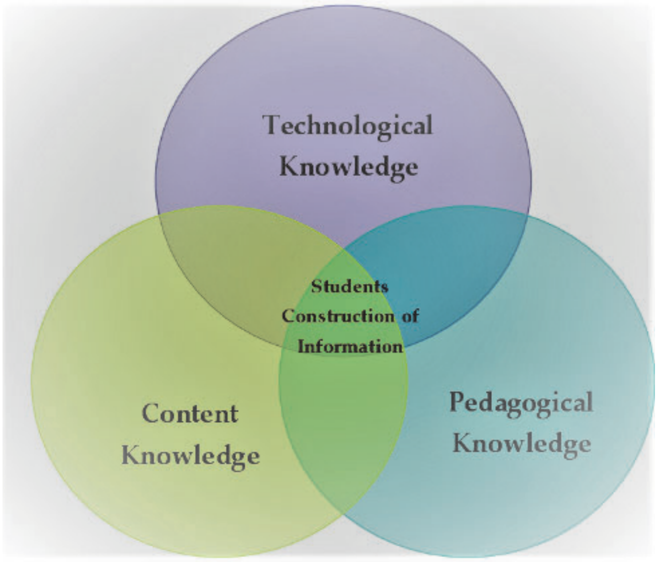

Figure 1. Pierson`s model [3]

In the new context, in order to fulfill their new roles, teachers had to shift their focus during the class from lecturing to assessment. Inquiry-based teachers become evaluators to “help diagnose students’ prior knowledge, measure students’ knowledge on comprehension experience and guide instruction, and measure their understanding and knowledge at the completion of the learning experience” [7]. In other words, the facilitator maintains the focus on learning, moves the process forward, measures the challenge, and provides appropriate feedback to the student and to the whole group [8]. Some authors have succeeded in proposing technology-enhanced teaching-learning models [9] [10] [11] [12].

At the system level, technology-involved teaching involves four primary components: the students, the instructor, the information content, and the technology tools[13]. An analysis of each component highlights some issues that should be taken into account in order to integrate the technology as efficiently as possible. For example, content can be analyzed from the perspective of learning outcomes and of the studied discipline. Pre-service teachers draw on their personal experience with technology, taking into account the time allocated to planning, teaching and their vision of their role in the teaching-learning process[14]. Students must be carefully screened, their exposure and access to technology, and their learning styles must be considered. Finally, technology can be called upon and analyzed according to its functions[15].

This way of approaching teaching and learning, through technology, considers the integration of the four component parts and the need to change all of the remaining 3 parts as a result of change occurring in one part in order to achieve the initially set objectives.

In the process of integrating technology into their curriculum, teachers encounter various barriers, Ertmer proposing a classification of them into two main categories:

- external barriers (e.g., equipment, time, training, and support)
- internal barriers (e.g., teachers' core beliefs about teaching and learning) [10].

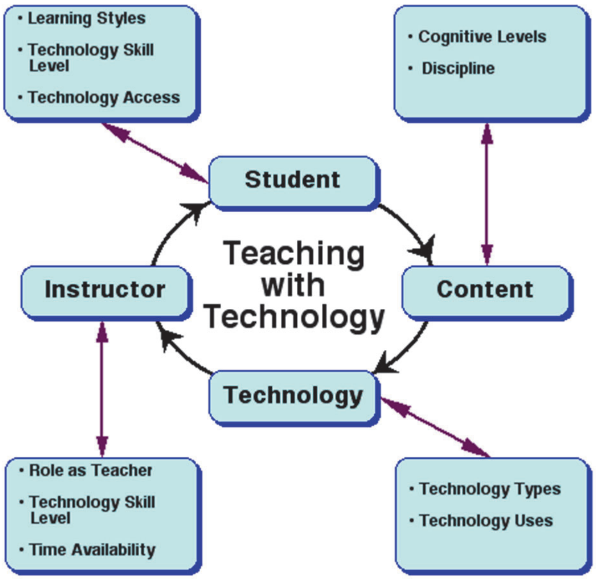

Figure 2. Teaching with technology model [10]

In order to analyze how the changes imposed by the COVID-19 pandemic affected the pre-university education system, the authors focus on identifying and highlighting the ways how teaching activity reorientation took place and how the modification of the perceived roles and the changes brought by the online education felt by the teachers from a high school in Iasi County, Romania.

2. EXPERIMENTAL PART

The qualitative method used to conduct this study was the semi-structured interview. The interview is one of the main ways of approaching reality in qualitative research. In the case of qualitative interview, the answers are relevant by themselves, as an expression of the subjects' perceptions and experiences[16]. The advantages of the semi-structured interview derive from:

- the possibility to explore attitudes and affective characteristics expressed in a natural form, specific to the person under investigation;
- the fact that the structure and motivational dynamics of the person can be understood in relation to certain situations;
- the possibility to study phenomena or events whose complexity is not easily approachable by standardized methods;
- fostering closeness and trust between the researcher and the investigated person, which allows the approach of sensitive subjects [17].

The present study is based on the empirical theory model. This approach refers to the inductive development of a theory, which is derived directly from the body of data collected in the research process. For Frost, Nolas and Shinebourne the empirical theory method is a way to study actions and interactions between phenomena, being advisable to answer event-oriented questions (e.g., "what is happening?", "how is it explained?", "why is it happening?" etc.) [18]. If the process is well performed, then the resulting theory perfectly fits at least the collected data set, without necessarily claiming to be generalized to another data set.

The semi-structured interview was applied to a sample of 8 (eight) teachers from the "Mihail Kogălniceanu" Miroslava Agricultural Technological High School, from Iasi County, Romania. The teaching staff at the institution mentioned above is reduced compared to other institutions in the sense that there are 32 teachers, of which only 28 are of the basic standard in this high school. The sample therefore represents 25% of the total number of teachers, a significant and, at the same time, representative sample for this technological and agricultural high school. The sample was made up of teachers who teach the following study subjects: Economic disciplines - 2 teachers, Food industry - 2 teachers, Romanian language and literature, foreign languages - 2 teachers, Biology - 1 teacher (in the unit there is only one biology teacher), Animal Husbandry

- 1 teacher (in the unit there is only one teacher of animal husbandry disciplines). The interviews were audio-recorded and fully transcribed. The interviewed teachers gave their consent for the audio recording procedure, and they were correctly and fully informed about the data use.

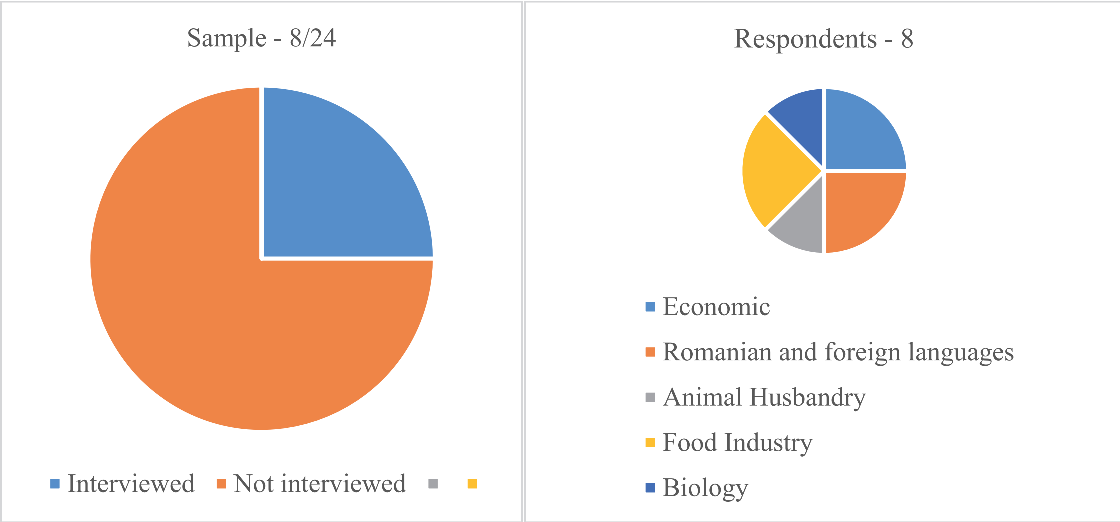

Figure 3. Study sample distribution

3. RESULTS AND DISCUSSION

3.1. Results

The first stage of processing the information collected during the interviews was the script transcription of the audio recordings. After fully transcribing the interviews, they were carefully re-read in order to identify common elements and differences between the answers given by the respondents. All 8 respondents are dedicated teachers who love teaching. Five of the eight respondents (62.5%) put the interaction with high school students in the top of their preferences in the activity of a teacher. The teachers at the "Mihail Kogălniceanu" Agricultural Technological High School believe that in-depth knowledge of students and family situations are prerequisites for students' success. The second question - "How would you describe yourself as a teacher?" - revealed the close connection that teachers have at the "Mihail Kogălniceanu" Agricultural Technological High School in the sense that all the eight interviewed teachers identified, in addition to the roles - obviously, indisputable - of transmitter of new scientific content, of promoters - the counselor, empathizer role. At the same time, in favor of balancing this emphasized role, as an adviser, the teachers of the Miroslava Agricultural Technological High School appreciated that they have a strong role of leader and manager in the classes where they teach and/or are conductors.

The third question - "How would you describe your relationship with the students?" What is the relationship with the parents?" - brought to the surface the specificity of the teacher-student-parent relationship. Teachers are aware of their leader role in the educational process, but they appreciate that this role is sustained by the support and collaboration with the family. Thus, teachers (as representatives of the school institution) and the family represent the two pillars of resistance on which education rests. The two professors who teach economic subjects, although with a notable difference in their experience at the department, appreciated the challenging nature of online teaching, but avoided positioning themselves in a specific part, preferring to analyze the advantages and disadvantages of online teaching. All the interviewees declared that the content of the subject matter taught in online education was largely , but they emphasized that this did not facilitate the achievement of the educational objectives, as they were achieved in a much higher proportion in traditional education compared to online education. Teachers' responses highlighted several areas where there were differences between traditional and online teaching:

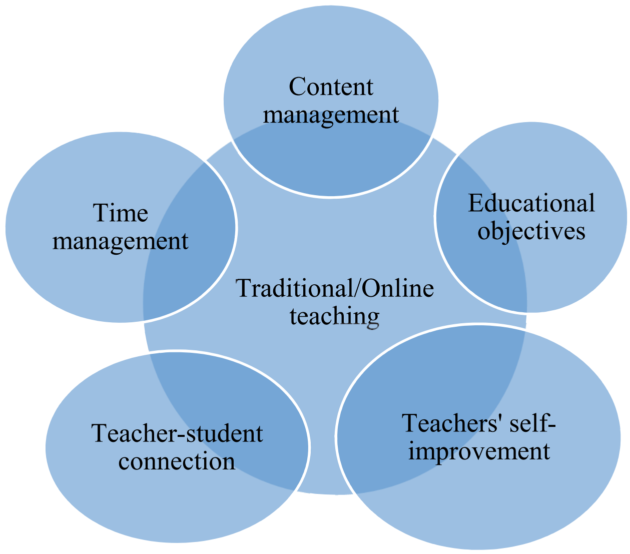

Figure 4. Traditional vs. online teaching

1. Time management - regarding this aspect, the majority of the interviewees felt that they managed their 50-minute online lesson much better for the following reasons: apathy/demotivation of students in online teaching in the sense that they no longer had the same attitude of involvement during the lesson; quite high absenteeism caused either by the lack of the device, or by the lack of internet, or by the lack of signal; the consistent diminution of the empathic, advisory role of the teacher led to an emphasis on the role of expert in the educational act.

2. Content management - the teachers reported that in online teaching content management was also better than in traditional teaching because they managed to transmit, with the help of digital tools, a large volume of knowledge in a much shorter time, shorter than it would have been in traditional teaching.

3. Regarding the achievement of the educational objectives - although online education came "packaged" with many digital resources appreciated by teachers as useful, attractive, efficient -, the teaching staff considered that these were not achieved in online education at a satisfactory level; for this reason, upon returning to the classrooms, teachers noticed many gaps in the students' theoretical knowledge. For some subjects of study, there were available textbooks and digital aids prior to the pandemic. Another aspect that favored the low achievement of educational objectives in online teaching was related to the fact that technical subjects have, in addition to the theoretical part, a laboratory part and a practical part. Even if the teachers used all their imagination and creativity, some of the practical activities were impossible to be held online.

4. In terms of the teacher-student connection, the interviewed teachers considered that it exists mainly in traditional teaching, being mostly absent in the online one, with the exception of Ana (zootechnician) who explains that she made efforts to maintain this connection with the students, being aware of the implications of this aspect in the life of the twelfth-grade students, who were going to pass the maturity exam.

5. Teachers' self-improvement - two of the teachers interviewed stated that they felt forced, constantly pushed in online teaching to improve themselves either on the side of acquiring new IT skills, or on the side of identifying, selecting the most effective digital materials to be able to maintain students' motivation (which was rapidly decreasing).

3.2. Limits and future research directions

Although the obtained results are very valuable, the present research also has some limitations. First of all, the sample used did not include mathematics, chemistry, physics, psychology, physical education and sports teachers. Their perception can represent the basis of a subsequent study that complements the findings of this research. Secondly, the results of this research may differ from those describing the same situation in other agricultural and/or technological high schools. Moreover, knowing that there are substantial differences between theoretical and technological/agricultural high schools, it is very likely that teachers in theoretical high schools have different perceptions than those shown in the present paper. Lastly, considering that the challenge of teaching online was a global one, it can be assumed that teachers from other countries have a different perspective on the issues researched and presented in this paper, taking into account the economic and social differences, the different endowment of the educational institutions and not lastly, the digital skills of teachers and students. The perception of teachers who teach other subjects than those included in this research may be different, but would help to make a general picture to draw the overall image in order to find solutions to improve teaching through the integration of technology.

The present research can be also extended at international level, especially in the countries form Eastern Europe, where the teachers were forcibly and suddenly challenged by the sudden transition to online teaching. Hence, the integration of technology into pedagogical practice should be further explored to support and sustain the transformation and professional development of teachers (especially in online education). Because access to teachers' perspectives is essential in examining transformation, data can be collected using methods such as observation or interviews. Furthermore, action or participatory research methods can be used to engage teachers in research processes as they investigate their own transformation and reflect on their practices, perspectives and assumptions. While studies of teachers' online experiences represent important exploratory research, future research should also focus on how collective transformation occurs within organizations and communities. It should also investigate the different ways in which teachers, communities and organizations are transformed through online learning initiatives and the roles different actors have in creating content, values and practices during this transformation.

4. CONCLUSIONS

Online teaching and the sudden manner in which it was introduced strongly challenged both teachers and students from "Mihail Kogălniceanu" Agricultural Technological High School from Miroslava, Romania. The challenges felt by the teachers were related to several aspects:

- the lack of knowledge (training) to use digital platforms and tools (both students and teachers);
- the lack of devices and the technical problems that manifested mainly among students; what is very interesting is that most of the students who come from rural areas represent social cases and do not have the economic opportunity to buy, from their own funds, digital devices;
- the lack of contact with students (spiritual, emotional, and even visual);
- increasing absenteeism linked to demotivation;
- going through all the scientific content and achieving the educational objectives.

Some of the above challenges have been overcome, but for some this was not possible. For example, the lack of IT skills was overcome through self-learning, the lack of devices among students was reduced by finding solutions to provide devices for some of the socially disadvantaged students. Either way, the lack of contact could neither be overcome nor replaced. For this reason, the teachers testified that there was an emotional and psychological imbalance caused by the imposed isolation, the lack of socialization between teacher and student, student and student, or teacher and teacher. This aspect led to the diminishing of the advisor role that a teacher normally has.

At the opposite pole, positive aspects related to online teaching and implicitly lessons were also identified. A first such positive aspect is related to adaptation to new conditions. Even if initially, there were difficulties, the teachers found solutions to digitize the teaching process and move it online, almost instantly; a second plus is related to the acquisition of digital skills - although they did not benefit from training, the teachers managed (mostly) to improve themselves in order to transmit the contents; another appreciable aspect is related to the amplitude of the digital materials created in those 18 months of online teaching. These materials are particularly useful and have also been integrated into traditional, face-to-face lessons.

The period of online teaching also came with a major benefit at the level of the educational unit, a benefit that, moreover, turned into an element of innovation that improved the instructional-educational act at the "Mihail Kogălniceanu" Agricultural Technological High School, namely the endowment of all classrooms with smart TVs. These devices are now used daily by most teachers during the class and students are captivated by the use of digital tools in traditional lessons.

Even though, for a year and a half, the "Mihail Kogălniceanu" Agricultural Technological High School closed its doors (like all pre-university educational institutions in Romania), and online lessons became the new normal, the education did not stop at the school gate, and the teaching staff did everything in their power during the pandemic to ensure that the students remained connected to the school, trained and motivated in the learning process.

The pandemic did not generate new challenges in the Romanian educational system but amplified them, in the sense that the inequalities in education deepened, the relevance to a constantly changing labor market decreased, as did the budget allocated to education. Although online teaching was a challenge for the entire pre-university education, in agricultural high schools, where the students mostly come from disadvantaged backgrounds, social differences were amplified. The closure of schools caused by the COVID-19 crisis has put pressure on the education system and there has been a decline in learning, an increase in dropout and early leaving of the education system, especially among the most vulnerable students, but also a rate of functional illiteracy higher by 10% compared to the period before the pandemic. In the same direction, UNICEF warns that the level of learning losses is "almost insurmountable" [20].

The period of online education created difficulties for many teachers, students and families: stress and anxiety, student demotivation and organizational problems for schools and families who had to juggle remote support devices. It also meant new difficulties for some of the most disadvantaged students, such as those living in poverty, the institutionalized and the disabled. Some of these difficulties were access to technologies for distance learning, isolation from classmates, and loss of support for access to study programs. The present research clearly showed that the "Mihail Kogălniceanu" Agricultural Technological High School faced online teaching with great difficulty, not being prepared for this situation in terms of resources. Of course, a high adaptability of the teachers was noted, who used their own resources and learned to use educational platforms and digital tools, in record time, to manage to keep the teaching-learning process active. Although the teachers pointed out many advantages and arguments in favor of online education, it cannot be neglected that educational objectives were not achieved, nor the emotional impact, both by teachers and students.

Thus, the Agricultural Technological High School Miroslava should focus on two directions of action:
1. provision of digital resources for all students (tablets, laptops with internet and courses for their use);
2. the development of effective counseling programs both for teachers and especially for students aimed at overcoming the emotional "lock-down" period and preparing for a new similar situation (possibly a new wave), as well as the development of school motivation to cover the gaps created during online education.

In this spirit, Robert Jenkins, UNICEF's Head of Education, stated: “While it is necessary to end disruptions to education systems, simply reopening schools is not enough. Students need intensive support to catch up on learning losses. Also, schools must go beyond their basic role and contribute to rebuilding the mental and physical health, social development and nutrition of children"[19]. Otherwise, in the next 10 to 20 years the world will witness a drastic skill` decrease on the labor market, which would have a devastating effect on Romania's economy, an economy that has already been heavily tested throughout history.

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CONNECTED FACTORY: DIGITAL SOLUTIONS FOR SMART PRODUCTION. CASE STUDY - BRAICONF 4.0

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***Abstract**. Romania has a rich tradition of textile production dating back centuries, the country being known for its skilled workforce in the textile and apparel industry. Like many other countries, the Romanian textile industry faces challenges such as competition from low-cost manufacturing centers, changing consumer preferences, and the need to adopt sustainable practices, this becoming an increasingly important aspect with a growing focus on environmentally friendly practices and materials. Connected factories are progressively making their mark in the textile industry, reshaping traditional manufacturing processes into smart, data-driven production systems. Digital solutions play a pivotal role in smart textile production by revolutionizing traditional methods, while optimizing manufacturing processes, enhancing quality control, enabling customization, and supporting sustainability efforts. The present research paper analyzes the complete integrated solutions identified for optimizing the production at Braiconf S.A. and is based on an internal evaluation conducted between January and March 2019 and contributes to the development and enhancement of the retail activity, the increase of the MTM activity, the attraction of customers with higher quality level and the increase of the productivity of the production lines. The 2019 assessment was considered in the research, given the reference year for the peak of textile industrial production, while the pandemic and post-Covid period represents the decline of the textile industry. The latter period is complemented by reviewing the scientific literature to the present, reiterating the importance and impact of digital solutions in smart manufacturing. Analyzing the efficiency of the departments and using the specific risk management methodology, we aimed to establish solutions adapted to the reality of production in order to improve the products and to optimize the processes, thus increasing the competitiveness and productivity of the company.*

***Keywords:** management, textile industry, connected factories, entrepreneurship, smart production*

1. INTRODUCTION

The fourth industrial revolution, known as Industry 4.0, describes the modern era in manufacturing, based on interconnected concepts and technologies, capable of continuous operations in a single space while optimising the same stock of products. Researchers such as Kamble and Muller [1,2] have demonstrated in their studies that Industry 4.0 has added value to the concept of sustainability in areas such as automotive, textiles and chemicals. While optimising workflow through innovative procedures is a novelty compared to the traditional methods that have built today's large companies, the industrial revolution also brings a number of challenges, such as strategic planning, financial, risk management .

The textile industry strongly influences a country's economy, considering that it is one of the largest industries worldwide. Maintaining competitiveness and ensuring the survival of production regardless of economic fluctuations are interdependent on the provision of the necessary labour force, the supply of basic materials specific to the finished product and the improvement of technology and machinery in order to optimise work time and production flow [3].

The explosive development of technology in the textile industry has also triggered a shift in people's preferences towards a super-functionality that surpasses economic value and the prevalence of the contactless society, so that traditional fashion has had to adapt in an accelerated manner to digital solutions, assuming the volatility, variety, complexity and speed of today's dynamics [4-6].

In order to maintain and consolidate a leading position in the market, digital transformation is not only necessary but should be seen as a logical step in the evolution of the companies, going beyond the predominant reticent vision in the textile sector, which, from a risk management point of view, represents a major risk factor in the stagnation or decline of a company [7].

The Covid crisis served as a wake-up call, raising awareness of the importance of implementing digitisation processes [8]. In the framework of the European Apparel and Textile Confederation EURATEX 2020, a plan organised in coherent short and long term measures was discussed, such as the need for investment in sustainable and innovative textiles, the need to educate and qualify young people in the textile industry to reduce the ageing workforce in the industry, the testing of digital manufacturing systems and the digitisation of the supply chain, the need to ensure free trade based on sustainable, repairable and recyclable products and others [9].

Several countries have expressed their vision regarding the transition of the textile industry in the coming period toward Industry 4.0 goals.

Germany, in its vision for implementation by 2030, aims to relocate digital production to flexible automation in order to solve the problem of the shortage of skilled labour. At the same time, the country's strategy focuses on addressing customer demand for environmentally friendly products, transforming factories into smart, networked factories with networked machines [10].

India, with a strong history in the textile industry has shaped its development strategy around importing special fibres with lightweight, durable and thermally stable characteristics, creating a mega textile park with an ecosystem focused on technology, research, development, incubation of start-ups, and supplementing funds for engineering and masters programmes in technical textiles [9,11].

Sweden, on the other hand, plans to work on developing mechanisms for improving the collection, reusability and the recycling of used textiles by providing economic support to collectors and sorting centres, focusing its development plan for the next few years on the global used textile sector and its involvement in reuse and recycling [12].

China's strategy in the textile industry is based on considerations such as the deterioration of the export market but also on uncertainties caused by the political context, so the country's main objective is to maintain the current capacity of the textile industry, representing 50% of the world market, and to create an industry focused on high technologies and sustainability-oriented clothing. Last but not least, France's vision aims to mobilise almost €35 billion to promote 37 eco-friendly, cohesive and competitive industrial projects in the textile industry [9,13].

Different countries are pursuing the expansion of the textile industry towards a technical, intelligent and sustainable one, with a focus on the workplace, the business concept and the smart factory design, which enables internal coordination and networking, communication between machines facilitated by digital technology, and processes optimised by artificial intelligence [14].

The present research focuses on implementing solutions specific to Industry 4.0 concepts within Braiconf S.A., a Romanian company founded in 1950. The solutions analyzed in the present study are the result of an internal analysis conducted in 2019, a period considered the peak of industrial productivity in Romania.

The challenge of identifying optimal solutions is defined by the fact that Braiconf S.A. operates on an organization based solely on people and not on systems and procedures, data is double-entered thus missing key information such as stocks, means of control and analysis, the procedures used consume time and energy and, last but not least, there is a risk of bottlenecks if key people leave the company.

Braiconf 4.0. implies a shift from LOHN system to finished product, full customer service, in-house collections, shorter delivery times, higher quality level, centralized data and standardized system-based procedures.

2. EXPERIMENTAL PART

The research model that underlies the identification of potential solutions based on the analysis of each department and the specific risks of each activity is shown in the figure below (See Figure 1), where LS Retail involves all-in-one modern digital retail software solutions for managing direct sales from own stores, Retroplanning implies the use of a critical path system that transforms the people-based organization into a system-based organization, MTM & MTO offers B2B and B2C solutions through an automated order processing system, and TAKT MANAGER provides production optimization and tracking with RFID technology.

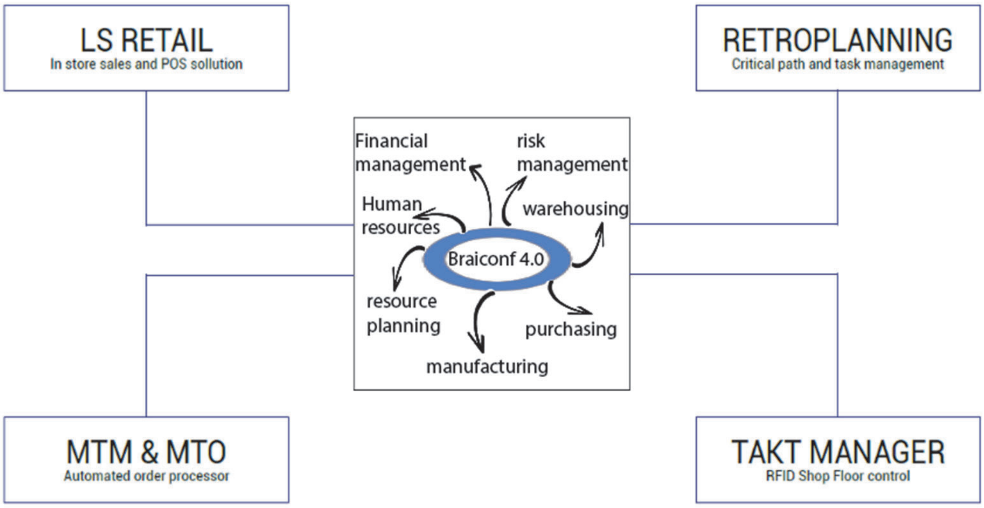

Figure 1. Conceptual framework

The risk management plan process is the project's strongest instrument for risk management, as it sets out each activity that the project management team needs to address to effectively handle project risks and uncertainties. It acts as a guidance that provides documented procedures, techniques and guidelines for the project management team to use while addressing the project.

3. RESULTS AND DISCUSSION

Table 1 summarizes the project's risk management plan as well as the information contained in it.

Table 1. The risk management plan

Braiconf 4.0	Objectives: Development and optimization of retail activity Significant growth in both B2B and B2C MTM activity Attracting higher quality customers with small orders Increase productivity of manufacturing lines
Risk management scope and objectives	Thresholds Prioritization of project objectives Weights and other parameters
Risk activities	Risk identification Risk evaluation Risk response plan Risk monitoring and control
Responsibilities and functions	Risk owners

The risk management plan describes the inputs, techniques and instruments used and the outputs to achieve project success. In conjunction with this analysis, a qualitative risk assessment and an identification of potential risk responses was also carried out to provide a broader overview of the risks that were identified (See Table 2).

Table 2. Inputs, risks, instruments and techniques based on the risk management plan

Input	Risks	Tools and Techniques
Efficiency	Stock shortages Sales loss Poor customer service Generating too much stock in the warehouse due to poor sales analysis Delayed deliveries to MTM due to manual processing Human errors in MTM processing patterns	Integrated retail - stock - production - accounting system Precise barcode management Replenishment decisions based on sales statistics. Reservation and transfer system between shops Centrally managed pricing Increasing the quality of both services and products through the automated MTM system
Raw and auxiliary materials management	Inefficient supply Risk of blocking production launch due to lack of raw materials (or delay in launch) Incorrect finished product cost calculations Possible mismanagement or even undetectable theft Limit on increase in volume of orders processed	A single centralized management system Management documents automatically generate the related accounting notes Receipts based on supplier orders and shipments/transfers based on generated delivery orders
Raw and auxiliary materials supply	Constant increase in the value of unaffected stocks Stock shortages for production orders Purchases started late when waiting for confirmation of stock in the warehouse Risk that the price invoiced by the supplier is higher than negotiated Possibility that suppliers send different quantities than ordered (smaller or larger)	Very precise supply system based on rules of supply, stocks, different prices depending on quantities, open orders, forecast Automatic checking of all exceptions generated by suppliers
Technical	Risk of human error or misinterpretation of measures and options Risk of technical bottlenecks due to a higher volume of orders during the peak season	100% automatic processing of MTM orders, collections and even small batches eliminates the risks of human error The processing time of an MTM order is a maximum of 3 minutes from customer validation on B2B
Foreign Trade	Delivery times affected Inability to prevent risks generated by customers: risk of non-payment, overdraft of current balances, credit insurance or credit limits	The integrated system provides customer care staff with the tools and information they need to inform customers on the status of orders, deliveries, payments, etc. Generation of packing-lists and automatic invoices
Production and planning	The whole organization of departments and production lines depends on this person who gathers data Due to the lack of centralization of data, possible errors are very difficult to detect. Increasing the number of orders can generate bottlenecks/delays at this level	Ensuring the workflow and filling in the information in the centralized system is done by each department. Any error or omission in one department will be immediately detected in the next department in work process All data is gathered and gradually filled in the system according to the evolution of the order
Financial / Accounting	High possibility of generating errors in declarations, payments, receipts Difficulty and uncertainty in financial reporting to management	The volume of data input by accounting will decrease significantly. Accounting staff will be more focused on control and efficiency. Reporting is done in real time

4. CONCLUSIONS

Setting objectives and identifying risks within them, as well as outlining techniques and highlighting the necessary tools, highlights not only the potential of Braiconf S.A. to achieve the parameters of Industry 4.0, but also the national guidelines that define the need for Romania to maintain international competitiveness in the textile industry.

Given the company's tradition but also the advanced average age of middle-management staff, the transformation of work processes based on systems and procedures is one of the most urgent solutions, given the risk analysis performed.

In addition to the risk analysis performed on the Braiconf S.A. Company and the solutions identified in the present research in order to achieve the Industry 4.0 objectives, further research is needed in order to establish directions at the decision-making management level, so that operational costs are reduced and productivity may demonstrate constant growth.

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LEAN SIX SIGMA AND SUSTAINABILITY IN TEXTILE INDUSTRY: A SYSTEMATIC LITERATURE REVIEW

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Abstract. *The purpose of this researchis to determine the relationship between Lean Six Sigma tools and Sustainability on textile industry. The research approach used in this analysis was a systematic literature review to identify what types of Lean Six Sigma tools have an important and significant role on sustainability in textile industry. The goal of the study was to develop a theoretical framework for the integration of the Lean Six Sigma tools and Sustainability indicators in textile industry.The results of this study show that Lean Six Sigma tools has a positive impact on Sustainability in textile industry by improvement productivity, reduce costs,quality and rework cost in the economic performance; in environmental performance by waste water, energy and resource usage;in social performance, by safety in the workplace,culture using the tools approach..*

Keywords: : *manufacturing, textile industry, reducing resources, performance,tools,lean.*

1. INTRODUCTION

The textile industry is considered to be the most wasteful at all stages of production.Sustainability has becom a fundamental concern for textile manufactures. There is a need for companies to focus on sustainable production and have sustainability goals.

The primary goals of the textile industry are to reduce costs, get faster service with less equipment, time, and employee labor, eliminate waste and non-value-adding activities in production processes.

Lean manufacturing is a set of te techniques and tools to eliminate waste from the process. Six sigma is a methodology aimed at reducing process variability [1] . The concept is known as Lean Sx Sigma(LSS).

LSS in textile industry focusses to remove defects , minimize variability from the process and customer service and eliminate non-value-added activities[1,2]

LSS is a methodology to improve quality ,reduce cost, efficiency, flexibility, time by focusing on the process performance.[3]

The philosophy of sustainability integrates three pillars: economic,social and environmental,becoming a goal for any organization.

As indicated by the Brundtland " sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"[4].

The textile industry benefits from the successful implementation of Lean Six Sigma (LSS) as it reduces costs and resources. Additionally, companies can improve social and environmental performance by ensuring worker health and safety, reducing pollution, and improving resource conservation.

The purpose of this research is to identify which LSS tools are implemented in the textile industry and how they impact the achievement of sustainability goals. To achieve this, the research present articles scientific related to the practices and tools that explain how LSS is integrated with sustainability in textile industry.

The structure of the paper is as follows:

1. Analysis of the literature on LSS instruments that have been successfully implemented in the textile manufacturing with the objective to identify indicators of sustainability.

2.A theoretical model for integrating the LSS manufacturing and Sustainability in textile industry.

3.The results achieved and discussions.

4. The conclusions of this work.

2. EXPERIMENTAL PART

In order to reach the defined goals, this paper was structured into 6 steps:

Steps of research methodology:

1.To indentify the articles in academic databases considering the keywords of the topic

2. To analyze, select the articles found in the first step and to exclude irrelevant articles

3.To analyze and synthesized the literature of the topic considered

4. To developing a theoretical framework for integrating sustainability and LSS tools

5.To identify the compatibility between LSS tools on sustainability in textile industry

6.To propose new avenues of research in this area

This research work is obtained from Google Scholar used to access and search the literatures needed. This paper is based on research literatures published from 2018 to 2023,filtered and adapted to topic.Articles collection is based on the textile industry.

Table 1

Benefits implementation the LLS tools in textile industry

Article identity	Tools	Benefits
(Prasad ,Dhiyaneswari , Jamaan, Mythreyan & Sutharsan,2020) [5]	Visual controls, Poka-Yoke, Kaizen, VSM, 5S, and Kanban	• healthy development • worker efficiency • flexibility • improved process
(DINULESCU & DIMA,2020) [6]	DMAIC process	• increased production • innovation • increased quality • reduction waste of production, • improved customer satisfaction • community quality
(Nedra , Xu Jun , Nèjib & Jiajia,2022) [7]	visual management,5S, training, JIT, Kanban, SMED ,VSM, TPM , Kaizen,VOC,DMAIC , FMEA , PDCA,Pareto, CTQ	• problem solving improvement' with 62.14% • decreased quality issues (32.56%) • decreased of waste (31.26%)
Labarta-García, Vidal-Asencios & Collao-Díaz,2023) [8]	Kanban,5S and Systematic Layout Planning (SLP)	• increased the productivity • reduction cycle time • improved discipline
Adrian & Kosasih,2023) [9]	DMAIC process	• reduction the waste • reduction production cost • improved costumer satisfaction • improved productivity performance • developed organizational communication

Article identity	Tools	Benefits
(Leyva,Perugachi, Saraguro & Orges,2023) [10]	VSM,Pareto diagram,5S,Manufacturing Cells ,	• improving the work environment from 46% to 87%, eliminating the wastesthe • reducing the cycle time from 8'28" /pajamas to 4'55"/pajamas • increased production from 1.080 pajamas for month to 1.964 monthly pajamas • improved customer satisfaction
(Baptista, Abreu& Brito,2021) [11]	Kaizen, Kanban,5S,TQM	• reduction the waste • reduction production cost • improved costumer satisfaction • improved productivity performance • developed organizational communication
(Bakator, Ćoćkalo & Vorkapić,2018) [12]	JIT,Kanban ,TQM,5S,Kaizen,PDCA	• improved • productivity • increased business performance
(Jamal, Ali, Usman & Satti, 2022) [13]	Process Mapping, Lean Improvement, Kaizen,	• increased productivity • improved quality
(Yashini, 2020) [14]	Poka-Yoke, DPMO, cause and effect diagram, and OEE	• improved quality • increased efficiency
(İnce, Ayvaz, Öztürk & Kuşakcı, 2018) [15]	VSM	• improved customer delay by approximately 500% • improved time supply 43% • improved production efficiency and process
(Jesica ,Vasudeva & Konda ,2023) [16]	5S	• improved the productivity • optimized resource allocation for reducing waste • improved quality • reducing cost of production • ultimately increasing customer satisfaction, organizational improvement through enhanced innovation.
(Ahmed & Noraffandy,2023) [17]	Kaizen	• impacts on the work environment • impacts on the productivity of the workflow
Jocelyn , Hamed ,Muhamed & Nor,2021) [18]	VSM	• improved the social sustainability performance of organisations.
(Sebastian ,Javier ,Iliana ,Edgar ,Gino & Claudia,2021) [19]	5S,workstation design, process management	• waste reduction with an index of 21.63 • reducing rework to 11.58% of the implementation lean tools

Based on paper reviewed ,the LSS tools used most frequently in textile industry are JIT,TPM,TQM,Poka-Yoke,Kaizen,VSM and 5S.

The adoption of LSS tools have been selected from articles where they used most frequently for increases product quality, improve the productivity, increas customer satisfaction,improving processes.

It was found that research the literature on the use of LSS and relationship between sustainibility in the textile industry is limited . Research has particularly lacked in relation to LSS tools on sustainability pillars.

The LSS and sustainable development in the textile industry can contribute to performance operational on minimizing of resources and the cost; in social performance, by providing the health and security of employees, in environmental performance by removing waste, decrease environmental damage and increasing the efficiency of the resource use. This study proposes a theoretical model of LSS sustainability in textile industry, incorporating seven key tools for sustainability indicators, based on literature reviewed.

3. RESULTS AND DISCUSSION

The key tools used to determine the relationship between LSS manufacturing and Sustainiblity in textile industry have been identified in many research papers.

The analysis of the theoretical framework suggested in this study, which reflects the interaction of LSS tools and sustainable development, is described in detail in Section 3.1.

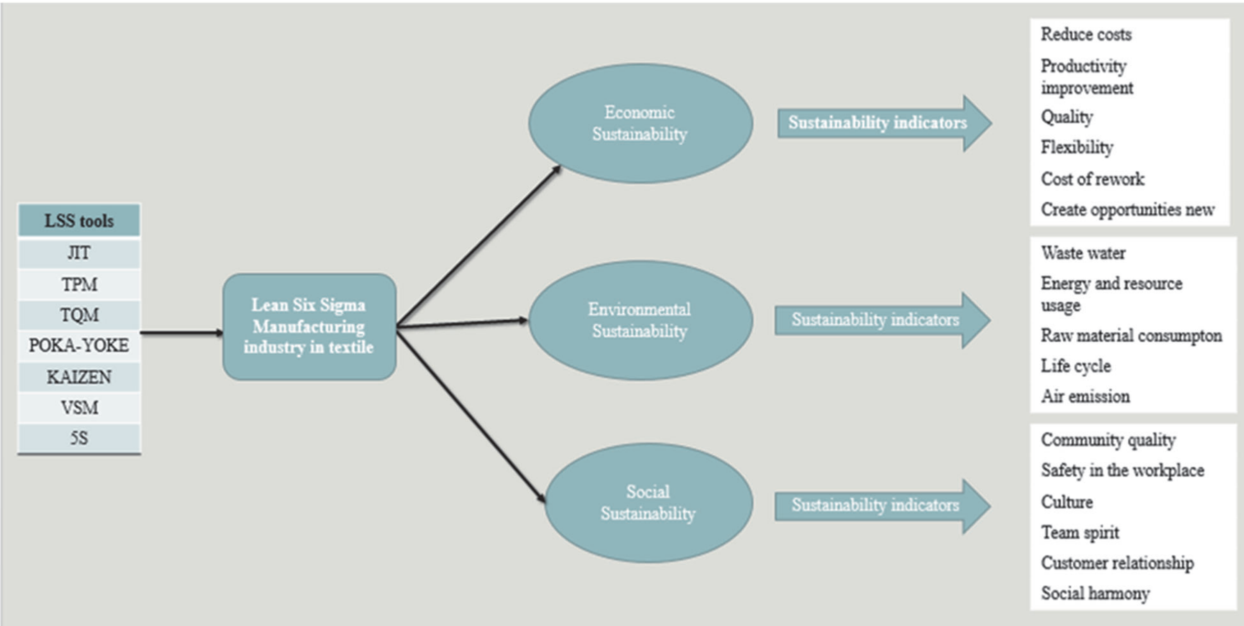

Figure 1- A theoretical framework for the integration of the LSS manufacturing and Sustainability in textile industry

3.1. LSS tools impact on sustainability in textile industry

In this study, we focus of the LSS manufacturing tools to highlight the relationship and impact on the sustainability pillars.

1)**Just In Time** (JIT) is a management approach focused on removing anything that does non-value adding, improved quality, increased efficiency and customer satisfaction , the principal objective is to minimize the stock.All these lead to economic, environmental and social sustainability.All these lead to economic, environmental and social sustainability.

2) **Total Productive Maintenance**: (TPM) is a method for maintenance that improves equipment efficiency, eliminates breakdowns to achieve the productivity and efficiency of a productive process with a positive impact on sustainable pillars.

3)**Total Quality Management** (TQM) is a management philosophy that focuses on identifying, minimizing, or eliminating errors in production., encourages all employees to eliminate waste, increase efficiency, and improve quality.

TQM is based on the JIDOKA: is a concept of automatically stopping the process if there are issues with the quality in the production line.

4) **Pok-Yoke** is a method for eliminating frequent workplace mistakes made by employees. Poka-yoke is an approach to quality control**.**

5)**Kaizen** is a method used to identify opportunities for reducing waste and variability in processes applying Lean and Six Sigma. Kaizen includes the reduction the defective numbers, costs, improving the supplier and customer relationships, employee skills. Kaizen is part of the employees work, thus contributing to achieving sustainability.

6)**Value Stream Map (** VSM) is a visual guide of the entire value chain , with the scope of analyzing and optimizing the entire process [10].

„The value stream map an analysis tool that is able to measure the dimensions of economic, environmental and social sustainability, showing time and energy, efficiency and health as well as safety" [20].

7) **5S**: is a cyclical methodology: sort, set in order, shine, standardize, sustain. It serves as a method for organizing, cleaning, and generating a productive work environment with an objective of eliminating remove of waste product and wasteful tasks. [10].

The 5Ss tool has various benefits, increased productivity, improved employee motivation, and a reduction in the risk of accidents..

The textile industry plays an important role in the economy and its activities have high environmental impact. LSS manufacturing has contributed to the trend towards sustainability by eliminating non-value adding activities ,to reduce comsuption of water,energy and raw material and the ability to obtain lower costs.

The LSS manufacturing textile is focused through the continuous improvement to reducing or eliminating the wastes and reducing variability the process. One of the main objectives of LSS is to eliminate waste that affects the environment.

Lean manufacturing removing all non-value-adding activities, for example: overproduction, overprocessing, transportation, waiting, inventory,correction,movement with positive impact on energy, emissions and water. The relationship between LSS and sustainability contributes to increased competitiveness and production efficiency in textile industry.

Economic sustainability is related to resource management strategies having financial results for a long time. LSS manufacturing leads to financial profits, competitive differentiation and reduces costs by reducing waste, reducing pollution, reducing costs, and when applying the philosophy and LSS manufacturig tools, leads to reduced production costs, improved quality, speed and flexibility.

Environmental sustainability has become an issue in the industrial environment in recent years as a result of high consumption resources , pollution and other environmental problems. The goal of environmental sustainability is to conserve resources and minimize the negative impact of business activities on the environment. Therefore, the textile companies apply LSS manufacturing to improve environmental practices.

Social sustainability: "The social dimension is defined as the worker's right to work in a clean and healthy environment through which they perform their assigned activities" [21]. Therefore, LSS reduce stress and increase independence with a positive impact on safety in the workplace and community quality.

4. CONCLUSIONS

This paper highlights the use LSS Tools to evaluate the relationship and impact on sustainability performance in textile industry. In-depth exploration was conducted to gain insight into organizational performance and social, economic and environmental impact.There is already a tendency in the textile industry environment to reduce the consumption of water, energy, raw materials and environmental waste.

The proposed theoretical model aim the correlation LSS sustainability indicators and textile industry performance.

The LSS tools used most frequently in textile industry to increase performance process and to reducing production waste are JIT, Total Productive Maintenance, Total Quality Management, Poke Yoka, Kaizen,Visual Stream Mapping and 5S. The significant indicators in the economic pillar are productivity improvement, reduce costs,quality and rework cost.The relevant indicators in the environmental pillar are waste water, energy and resource usage and the most significand indicators in the social pillar are safety in the workplace,culture.

Textile industries are already making changes in conventional processes. More investigation is required to understand the relationship of LSS manufacturing and sustanaibility in textile industry.

A theoretical discussion about LSS manufacturing and sustainability was addressed in this study to address the research needs in this area.

We have demonstrated the synergy between LSS tools manufacturing and sustainability in the textile industry, with focus only the few .

Future research should explore more LSS tools to improve performance social, economic and environmental.

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CHALLENGES OF SUSTAINABILITY ASSESSMENT IN THE MANUFACTURING INDUSTRY

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***Abstract**. Researchers and practitioners have been interested in the pharmaceutical sector over the years due to its significance and connection to a theme that is essential to human existence: health. The impact of the evolution of the pharmaceutical industry on people's lives is well established. This is due to the industry's significant role in promoting health and quality of life, as well as its status as a major polluter and one of the most relevant sectors for the global economy. Research in the scholarly literature on this topic reveals that the management issues and sustainability of pharmaceutical companies are only briefly and generally treated. Environmental sustainability is the state of balance, interconnectedness, and resilience that allows the satisfaction of human needs without jeopardising biological diversity. The well-being of individuals and communities, workplace safety and health, working conditions, human rights concerns, and labor rights are all included in the social dimension of sustainability. The economic dimension involves reducing costs through systematic management, research and development expenditures, investments in machinery and technology, or other forms of capital.In our research, we sought to find out how important sustainability is in a Romanian pharmaceutical company, if its managers have a sustainable perspective in organizing the entire production chain, and what the main challenges are. We talked with some of the managers of a pharmaceutical company, from the production area as well as from the project area, respectively human resources, more precisely with 15 managers, the discussion being in the form of an interview, and from the analysis we pointed out that among the three dimensions of sustainability special attention is paid to the environment and, at the same time, we discovered that in the pharmaceutical industry maintaining sustainability standards represents a great challenge.*

***Keywords:** waste, planet, clear production, sustainable management, social, economic.*

1. INTRODUCTION

The sustainability of society is a central concept in contemporary society, and the pharmaceutical industry assumes the responsibility of playing an important role in the field of a sustainable future. In this context, the vision of pharmaceutical industry on the concept of sustainability plays a crucial role in the implementation of appropriate practices and strategies to ensure the balance between medical progress and environmental protection [1].

Regardless of their size, location, or line of business, firms have been voicing their support for sustainable development more and more in recent years. Economist Milton Friedman said that, among all the responsibilities of an enterprise, the most important is profit maximization, which serves to reward and motivate shareholders [1].

Many modern scholars think that corporate social responsibility serves as the catalyst for numerous breakthroughs, even though new technologies and social behaviors are unquestionably the origins of innovation [2].

The link between sustainable development and sustainable innovation in companies is complex due to the influence of some parameters that can represent facilitators or barriers, as the case may be:

- The manager's attitude towards the different perspectives, the individual and often contradictory interests of the interested parties, and power games that arise from social positions

- The manager's inclination for social, but also technical and technological compromise.

An organizational vision appears to play a significant role in business success, as businesses with a well-communicated vision can achieve and maintain sustained competitive advantages over time over those without such a vision [3].

Since the appearance of the term "sustainable development" in the Brundland report of the United Nations in 1987, the need to assess sustainability both at the macroeconomic and microeconomic levels has been defined and developed. The definition of the three key aspects ("triple bottom line") of economic, social, and environmental sustainable development by J. Elkington in 1994 allowed the clarification and better operationalization of the concept. The Triple Bottom Line (TBL) is a concept used to evaluate the performance of an organization in terms of sustainability and its impact on the environment, social aspects, and financial outcomes. This concept promotes the idea that the success of an organization should not be measured solely based on its profitability but also on its contribution to social and environmental aspects [4].

The three components of the Triple Bottom Line are:

- Profit (Economic): This refers to the financial performance of an organization and the generation of sustainable profits. By efficiently managing financial resources, an organization can ensure its long-term sustainability and contribute to the economic prosperity of the communities in which it operates.
- Planet (Environment): This involves the organization's impact on the surrounding environment and efforts to reduce that impact. By adopting sustainable practices such as reducing carbon emissions, making efficient use of natural resources and protecting biodiversity, an organization can contribute to environmental preservation and prevent its degradation.
- People (Social): This refers to the organization's impact on the community and its employees. A socially responsible organization takes into consideration aspects such as human rights, safe and fair working conditions, diversity and inclusion, employee health and safety, and community involvement.

The Triple Bottom Line encourages organizations to consider their impact across all three dimensions and pursue a balanced and sustainable approach. By integrating sustainability into their strategy and operations, organizations can create long-term value for themselves and society as a whole.

Later, the mention of the term "corporate social responsibility" and business sustainability assessment frameworks intensified, and in 2002, sustainability assessment reached a new dimension by supporting the Global Reporting Initiative organization as a permanent formation by the United Nations.

In the scientific literature, many situations are documented in which business managers have a positive attitude towards the environment. According to a study carried out on 220 large and medium-sized enterprises in Great Britain, taken by Jansson [5], 82% of managers confirmed that environmental aspects should be a management priority, while 70% disagreed with the statement "business owners do not have social problems to solve". Other qualitative research have found that the manager's mindset, as well as his ethical values, are vital for an enterprise's commitment to sustainability.

Numerous research studies concerning the implementation of sustainable development strategies at the corporate level emphasize the significance of the manager-founder, whose individual values impact the company's strategic orientation and consequently the incorporation of social responsibility into the company's day-to-day operations [6].

The study aims to increase managers' awareness among pharmaceutical companies regarding the issue of sustainable development at the company level and identify new approaches to measuring and evaluating companies' social responsibility. It also highlights the complexity of the factors that affect sustainability at the company level and their interdependence, including with the company's external environment.

2. EXPERIMENTAL PART

Our study involves approaching the managers of a pharmaceutical company from its various departments in order to find out what their opinion is about the concept of sustainability and what the biggest challenges are that they face every day. Considering that the company on which we did the study is one of the production areas, it is part of the processing industry, namely the pharmaceutical one. It is divided into several production sections, each of which manufactures a certain category of medicines, starting from tablets, capsules, ointments, and injectable. Therefore, there are managers both in the actual manufacturing area and on the project side, in quality assurance and control, research and development, and, respectively, human resources. Interaction with each of these departments was desired, so the discussion was in the form of an interview with a number of 15 managers, and after obtaining information from them, we selected the main observations that helped us achieve the main objective, which was to find out the opinion of the majority regarding sustainability, challenges in the field of the pharmaceutical industry, and possible solutions. We didn't have a predetermined number of questions for each individual manager, the discussion being quite spontaneous, trying to find out as much information as possible depending on everyone's knowledge and the difficulties characteristic of the department they lead.

Each department comes with its own particular challenges. In our study, we noticed that part of the answers focused more on the social and economic dimension (characteristics of the human resources department or even financial) and the other part on the environment (where production managers have the preponderance).

Defining the concept of sustainability, the managers chose to describe it as:

Long-term orientation;

- Positive example;
- Adaptation;
- Quality of products and services;
- Coherent vision;
- Work productivity
- Corporate social responsibility;
- Information and awareness;
- Ethics/honesty in relations with partners, respectively reduced consumption of resources;
- Mutually beneficial relationship with the community.

The sustainability values of the manager were assessed using the New Ecological Paradigm (NEP) scale [7]. This scale uses a Likert scale with 15 items to gauge a group's interest in environmental issues. Table 1 presents the results of this evaluation.

Table 1.

Revised NEP statements

Revised NEP (New Ecological Paradigm) statements
1. The maximum population that the earth can sustain is drawing near.
2. When people interfere with nature, there are often disastrous consequences.
3. The natural balance is fragile and deteriorating.
4. People have the right to change the environment to adapt it to their needs.
5. The natural equilibrium is robust enough to endure the influence of contemporary industrialised nations.
6. Plants and animals have equal rights to exist, like humans.
7. The rules of nature govern mankind, even with their unique abilities.
8. Eventually, people will discover how to manipulate nature and how it functions.
9. Human creativity will find solutions so that the earth can always be inhabited.
10. People abuse the environment.
11. What we call the "ecological crisis" that humanity is facing has been greatly exaggerated.
12. Humans must control nature.
13. The earth is like a spaceship with limited resources and space.
14. If current trends persist, a significant ecological disaster is imminent.
15. As long as man can figure out how to use them, the world is full of natural resources.

This school is often found and used to measure pro-environmental opinions all over the world. A sizable portion of managers prioritizes environmental issues, according to the analysis of their answers to the two questions.

The most widely used environmental protection actions in daily life include recycling waste with the intention of repurposing it, repairing broken items rather than purchasing new ones, limiting the amount of food, clothing, and appliances that are consumed, and selective waste collection that occurs frequently and widely.

Managers of companies claim that they frequently organize and participate in collective waste collection activities, as well as in the cleaning of green spaces and the planting of trees in nearby areas or even within the factory premises.

Table 2 shows some indicators of sustainable development in the pharmaceutical industry, identified on the basis of the academic literature [8], which the managers who participated in the interview believe are important for measuring sustainability.

Table 2.

Indicators of sustainable development for the pharmaceutical industry

Social Indicators	Environmental Indicators	Economic Indicators
- Employee training - The frequency of work accidents - The staff replacement rate - Customer satisfaction - The ratio between female and male employees - Profit and taxes	- Energy consumption - Water consumption - Carbon dioxid emissions - Sulfur dioxide emissions - Residual water - Solid waste - Investments in environmental protection	- Fiscal value - Total profit - The share of the number of products in the turnover - Research an development expenses - Profit/Cost ratio - Net working capital

3. RESULTS AND DISCUSSION

The pharmaceutical industry is very complex and rigorous. Medicines are produced according to well-established standards imposed by agencies such as the FDA (Food and Drug Administration) or GMP (good manufacturing practice). As a result of our study, we find that the managers who deal with the management of the various departments of this industry face many challenges. The main observations from the discussions with them are:

- 90% say that one of the major challenges they face in terms of sustainability is the management of pharmaceutical waste, which can include chemicals, hazardous substances, and expired drugs that can have a negative impact on the environment and human health. They are forced to approach different techniques but also very rigorous procedures for the safe collection, treatment, and disposal of pharmaceutical waste.
- 80% consider that the well-being of employees is essential for the good functioning of the company.
- 75% of managers (from the production departments) say that the efficient use of resources is also a big challenge because the production of medicines can involve the intensive use of water, energy, and other natural resources. For this, they must identify and periodically implement measures to reduce the consumption of resources and, at the same time, optimize the production processes.
- Obtaining profit and protecting the environment are considered important by 89% of the respondents.
- 83% of managers consider that the well-being of customers is important and, at the same time, an essential characteristic of a sustainable company.

It's clear from looking at the above responses that they have a comprehensive idea of the company's sustainability. According to scholarly literature, each of their versions takes a distinct approach to addressing significant facets of the idea of sustainability at the corporate level. Thus, even though some of the managers are unaware of it, we may infer that they have a good deal of expertise on the subject.

There are several significant challenges to implementing sustainability in the pharmaceutical industry. Here are some of them also found in academic literature:

3.1. *Pharmaceutical waste management*: Pharmaceutical products can contain hazardous chemicals and expired medications that require proper disposal. Managing pharmaceutical waste in a safe and responsible manner can be challenging, as it involves costs, special handling, and disposal requirements [9].

3.2. *Carbon emissions and climate change impact*: The production and distribution process of medicines can involve significant carbon emissions. Reducing these emissions and minimizing their impact on climate change requires investments in cleaner and more energy-efficient technologies, which can be a financial challenge for many pharmaceutical companies [10].

3.3. *Natural resource consumption*: The pharmaceutical industry consumes significant amounts of water, energy, and other natural resources in the production process. Ensuring responsible consumption of these resources and exploring options for renewable sources can be a challenge given the stringent quality and safety requirements [11].

3.4. *Accessibility and equity in sustainability*: Implementing sustainable practices can bring additional costs. Understanding and addressing the impact of these costs on the accessibility and equity of pharmaceutical products can be a significant challenge to ensuring that all patients benefit from sustainable innovations in the medical field [12].

3.5. *Global coordination*: The pharmaceutical industry is a global industry, and sustainability-related challenges require coordination and collaboration at an international level. Different standards and regulations, inadequate infrastructure, and differences in implementation capacities can pose challenges in promoting sustainability across the pharmaceutical industry [13].

However, addressing these challenges can lead to innovations and sustainable solutions that contribute to environmental protection and ensure more equitable and sustainable access to essential medicines.

Considering that among the three dimensions of sustainability in the pharmaceutical industry, the environment is predominant in our case, represented by waste management, the responsibility with which natural resources are used, and the materials used in the manufacture of medicines,.

The actions to protect the environment and the measures that managers impose on the department they lead are of particular importance in achieving the concept of sustainability at the company level, but everything starts with awareness of the problems and eventually finding solutions.

In terms of details about the pharmaceutical sector and potential sustainable practices, research was conducted in Singapore, for instance, on the lubricants used in oral drug forms (tablets and capsules), which serve to keep the ingredients from adhering to production machinery when compressing chemical powders into solid tablets. There are varieties of lubricants on the market, and the most commonly used of these is magnesium stearate. These alternative lubricants are no longer commonly employed, despite the fact that many other lubricants (such as inorganic compounds, polymers, and surfactants) can offer lubrication efficiency that is equivalent to that of MgSt and frequently result in tablets with superior properties. A study was conducted that utilized environmental sustainability measures as one of the decision-making tools (together with tablet properties) in the lubricant selection process, as the pharmaceutical industry endeavors to enhance the environmental sustainability of its production. Four different lubricant types—MgSt, talc, polyethylene glycol (PEG 6000), and sodium dodecyl sulfate (SDS)—were used to produce ibuprofen tablets for the study. Through life cycle evaluation, the environmental impact of each lubricant's raw material production has been quantitatively evaluated. The life cycle assessment (LCA) of ibuprofen tablets made with various lubricants was then carried out. To get material and energy flow data for this work, kilogram-scale tableting experiments were conducted. The outcomes of the tableting trials demonstrated that the type of lubricant used had no effect on the properties of ibuprofen tablets, and all of the tablets were able to meet the requirements of friability, weight fluctuation, uniformity of drug content, and dissolving. PEG 6000 has the best environmental durability profile, according to the LCA data, followed by talc, MgSt, and SDS. Because polyethylene glycol (PEG 6000) has a better durability profile than magnesium stearate (MgSt), tablets made with PEG 6000 as a lubricant have a lesser environmental impact. Consequently, the manufacturing of pharmaceutical tablets can be made more environmentally sustainable by integrating environmental sustainability values into the lubricant selection process [14].

Above, we mentioned only one of the examples found in the academic literature that supports the concept of sustainability at the level of the pharmaceutical industry, which also demonstrates that although we are talking about an industry that has a high degree of pollution, there are solutions that can improve the situation so that companies in this industry can become more sustainable.

4. CONCLUSIONS

Following the study, it can be seen that the opinions are varied, but a fairly large percentage shows that the managers have knowledge of what sustainability means and try to find solutions so that the company they belong to operates in accordance with sustainability standards.

The biggest challenge is that of waste, because we are talking about an industry that generates waste from several categories, which are not easy to distribute considering that the vast majority are chemical substances that are unfriendly to the environment, with medicines also being from the same category. Here, difficulties can arise both with waste from the production departments and later from those who purchase in large quantities and remain with merchandise in stock that expires (pharmacies, warehouses, hospitals, etc.). And in this case, the company that produces the medicine is the one that should also have a suggestion to destroy it when it can no longer be administered by the patient.

Another important aspect of approaching the concept of sustainability in the pharmaceutical industry is community involvement and social responsibility. Managers must be aware of the impact they have on local communities and must develop strategies to contribute to their development. This can include corporate social responsibility initiatives, involvement in community projects, and promoting access to essential medicines in disadvantaged regions.

Training the staff in the correct management of situations like this is not exactly simple, because first of all, he must be aware of what it means to work for a sustainable company, and then he, as an employee of the company, makes a significant contribution if the procedure is applied correctly.

In addition to the actual waste, we are also talking about the high consumption of resources that is not easy to reduce. For example, water is an extremely important resource. The pharmaceutical industry is one where you work with high-tonnage equipment that needs to be cleaned periodically to ensure the optimal quality of the medicines. At the same time, the manufacturing is carried out in classified clean rooms that have an entire cleaning program, which can be carried out weekly or even daily, depending on the degree of risk for the manufactured medicine. Reagents used in analyses that are later channeled must also be neutralized so that they are not harmful to the soil. High-tonnage equipment not only consuming water but also energy, with some of them being disconnected from the source of electricity rarely or maybe only during the revision period.

Therefore, in the pharmaceutical industry, maintaining sustainability standards is a great challenge both for those who implement procedures (managers) and for those who must respect them and apply them rigorously.

We want, in the continuation of the study, to find out what improvement methods the managers of the company will propose so that it is a sustainable upward slope.

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