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Preparation of Nano-Sized Eucalyptus Leaves Extract and its Application on Cotton as Natural Dyes and Antibacterial Agents

Priprava izvlečka z nanodelci iz listov evkaliptusa in njegova uporaba kot naravnega barvila in protibakterijskega sredstva za bombaž

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Abstract

Nano-emulsions of *Eucalyptus globulus* leaves extract in 96% ethanol and 96% methanol were successfully prepared using the method of homogenization at various speeds of 13,000 rpm, 15,000 rpm and 17,000 rpm, with the addition of non-ionic surfactant to prevent agglomeration. A phytochemical analysis showed the presence of tannin, phenol and flavonoids. The size of the resulting nano-emulsions was measured using a particle size analyser (PSA) prior to the dyeing of cotton fabrics using the two-dips-two-nips method. Antibacterial tests were carried out on the extracts and dyed fabrics. The results showed that nano-sized particles (< 100 nm) were obtained from all extracts in both solvents used at all speeds. All dyed fabrics showed good levelness in a pale-brown colour with K/S values < 1 for all samples under spectrophotometric measurement. The colour fastness of the dyed fabrics to washing and rubbing were good to very good, with grey scale values ranging between 4/5–5. Antibacterial tests in *Staphylococcus aureus* bacterium showed that the eucalyptus leaves extract solution exhibited antibacterial ability, as evidenced by the formation of clear zones around the wells. Much better antibacterial activity was demonstrated by the dyed fabrics. Changing the particle size to nano increased the effectiveness of the antibacterial activity of the *Eucalyptus globulus*. Results showed that the nano-sized eucalyptus leaves extract demonstrated a more significant antibacterial activity than dyeability.
Keywords: *Eucalyptus globulus*, nano-emulsion, antibacterial, natural nano-dye

Izvleček

Nanoemulzije z izvlečki listov rastline Evkaliptus globulus v 96-odstotnem etanolu in 96-odstotnem metanolu so bile uspešno pripravljene z metodo homogenizacije pri hitrostih 13.000 vrt./min, 15.000 vrt./min in 17.000 vrt./min *in dodatkom neionske površinsko aktivne snovi za preprečevanje aglomeracije. Fitokemična analiza je pokazala prisotnost taninov, fenolov in flavonoidov. Velikost delcev v nanoemulzijah je bila izmerjena z analizatorjem velikosti delcev (PSA) pred barvanjem bombažnih tkanin z metodo dveh potopov-dveh stiskov. Opravljeni so bili protibakterijski testi na ekstraktih in obarvanih tkaninah. Rezultati so pokazali, da so vsi izvlečki pri obeh topilih in pri vseh hitrostih vsebovali nanodelce, velike manj kot 100 nm. Vsi proučevani vzorci tkanin so bili enakomerno obarvani v svetlo rjavi barvi in so pri spektrofotometričnih meritvah izkazali vrednosti K/S < 1. Barvna obstojnost pri pranju in drgnjenju je bila dobra do zelo dobra, z vrednostmi sive lestvice med 4/5 in 5. Protibakterijski testi na bakterijo Staphylococcus aureus so pokazali, da ima emulzija izvlečka iz listov evkaliptusa protibakterijsko aktivnost, saj so se na plošči agar tvorila inhibitorna območja okrog ločeno nacepljene testne bakterije. Obarvane tkanine so pokazale veliko boljše protibakterijske aktivnosti kot nebarvane. Velikosti delcev je dokazano povečala učinkovitost protibakterijske aktivnosti izvlečka iz listov Evkaliptus globulusa. Rezultati kažejo, da je ekstrakt nanodelcev iz listov bolj izboljšal protibakterijsko aktivnost kot barvno sposobnost.*

Ključne besede: Evkaliptus globulus, nanoemulzija, protibakterijski, naravno nanobarvilo

1 Introduction

In recent years, there has been increasing demand for the use of natural resources, driven by a global shift towards sustainability and environmental consciousness [1–2]. This trend emphasizes the importance of harnessing renewable and biodegradable materials for various applications, and reducing reliance on synthetic chemicals that often pose ecological and health risks. In this context, natural dyes and antibacterial agents derived from plant sources have garnered significant attention due to their eco-friendly nature and potential health benefits [3–4]. Research on the development of natural dyes therefore continues to increase and attract more attention because of the global requirements that tends to favour sustainable and environmentally-friendly materials [5–6].

Eucalyptus globulus, commonly known as the blue gum tree, is a well-known source of phytochemicals with a wide range of bioactive properties [7–8]. Traditionally, extracts from eucalyptus leaves have been utilized for their therapeutic properties, including anti-inflammatory, antioxidant, and antimicrobial effects [4, 8]. Recent studies have highlighted the potential of *Eucalyptus globulus* as a promising resource for natural dyes and antibacterial agents [9–10]. The rich composition of bioactive compounds, such as tannins, flavonoids and essential oils, in eucalyptus leaves underpins their ability to serve as an effective and sustainable alternative to synthetic dyes and antimicrobial agents [11–12]. In previous studies, Eucalyptus extracts were made and applied in macro or micro measures [13]. In general, dyeing with natural dyes results in poor colour fastness due to their low affinity for textile fibre [13–14]. On the other hand, the manufacture of dyes in nanosize is quite promising for further exploration, particularly due to its ability to increase the effectiveness and efficiency of the application process, including its ability to increase colour fastness [15].

The development of nano-sized particles from natural extracts represents an innovative approach to enhancing their efficacy and applicability. Nanosizing refers to the reduction of particle size to the nanometre scale, which significantly alters the physical and chemical properties of a material [15–16]. For eucalyptus leaves extract, nanosizing can lead to increased surface area, enhanced solubility and improved interaction with target substrates. These modifications are particularly advantageous in the context of dyeing processes, where uniform colour distribution and penetration are crucial, and in antimicrobial applications, where higher surface activity can result in more effective bacterial inhibition.

Nano-sized particles tend to easily agglomerate. To prevent them from remaining in nano-size, it is therefore necessary to keep them in the form of nano-emulsions by adding an emulsifier to the solution during homogenization [17–18]. In nano-emulsion systems stabilized by non-ionic surfactants, the surface charge comes from the adsorption of ions present in the aqueous phase or due to friction between droplets and the dispersion medium. The adsorbed ions on the droplet surface generate a coulomb repulsive force between the particles that will hinder aggregation [19].

Ideally, dyeing using nano-sized eucalyptus leaves extract gives higher colour strength, colour fastness and antibacterial abilities [20]. The aim of this work was therefore to validate this concept by comparing the quality of dyeing results using normal-sized extracts with nano-sized extracts [21]. This study focused on the preparation of nano-sized eucalyptus leaves extract and its application as a natural dye and antibacterial agent. By leveraging the nanoscale properties of the extract, the research aimed to demonstrate the improved performance and sustainability of natural products derived from *Eucalyptus globulus*. The findings of this research are expected to contribute to the growing body of knowledge regarding natural resource utilization and offer practical solutions that are in line with the principles of green chemistry and sustainable development.

2 Experimental

2.1 Materials

Six samples of nano-sized eucalyptus leaves extract were prepared from extraction using two different solvents, i.e. 96% methanol and 96% ethanol, which were then homogenized at three different speeds, i.e. 13,000 rpm, 15,000 rpm and 17,000 rpm. Two other control samples prepared from the extraction of the leaves with 96% methanol and 96% ethanol were added. The leaves of *Eucalyptus globulus* used for this research were obtained from an Indonesian state-owned forest plantation, Perum Perhutani KPH Jatirogo, East Java, Indonesia. Methanol (96%) and ethanol (96%) were purchased from Sigma Aldrich Indonesia. To prevent agglomeration during homogenization, two types of emulsifiers, i.e. polyethylene glycol 400 (Merck KGaA) and Tween 80 (Merck KGaA) were utilized in each process. The resulting nano-emulsions were then used for dyeing on 100% woven cotton (RFD or ready for dyeing) obtained from the stock in the Laboratory of Textile Physical Chemistry in Politeknik STTT Bandung.

2.2 Preparation of nano-sized eucalyptus leaves extract

The preparation of nano-sized eucalyptus leaves extract and the characterization thereof were carried out in the Nanotechnology and Microbiology Laboratories of the Indonesian Centre for Agricultural Postharvest Research and Development, Bogor, Indonesia. Fresh eucalyptus leaves that had been cut into small pieces were washed under running water three times, and then dried in an oven at 70 °C for 30 minutes. A total of 500 g of eucalyptus leaves (the total amount used for this research) were divided into two and macerated in each corresponding solvent (200 ml 96% methanol or 96% ethanol) for 48 hours. Samples were then filtered and evaporated at 70 °C to obtain pure extracts [22]. Eighty ml extracts were obtained as the yield from the total amount of leaves used.

Phytochemical analysis on the presence of the total tannin, phenol and flavonoid content was performed to the resulting extracts. For the tannin content analysis, a blank solution containing 0.5 ml of Folin Ciocalteu reagent and 1.25 ml of saturated Na_2CO_3 in distilled water (up to 25 ml) was prepared. Incubation at room temperature for 20 minutes was performed. Absorbance was measured using a UV-Vis spectrophotometer at λ = 725 nm. A stock solution of tannic acid was made by homogeneously dissolving 50 g of tannic acid in distilled water (up to 50 ml). A standard curve was developed from the measurement of absorbance of a series of four different concentrations of the mixture of tannic acid, Folin Ciocalteu and saturated Na_2CO_3 in distilled water, with the same incubation procedure. Total tannin content in each eucalyptus leaves extract was carried out by the same procedure, replacing tannic acid with sample eucalyptus leaves extract. Tannin content was expressed as mg of tannic acid equivalent/gram of extract, which was calculated from a standard solution regression curve. For phenol content analysis, a standard solution was also made by dissolving 1 ml of Folin Ciocalteu reagent in 10 ml distilled water, which was vortexed for 1 minute. Up to 0 ml of 7% Na_2CO_3 and distilled water were added to reach 25 ml. The mixture was incubated at room temperature in a dark room for 90 minutes. Absorbance measurements were carried out at λ = 750 nm. A stock solution of gallic acid (1000 ppm) was made, followed by the same procedure to create a standard curve. Total phenol content in each eucalyptus leaves extract was expressed as mg gallic acid equivalent/gram extract. Finally, the determination of flavonoid content was carried out by making blank solution of 3 ml of 5% $AlCl_3$ in 10 ml distilled water. The mixture was incubated at room temperature in a dark room for 90 minutes after being vortexed for 1 minute. Absorbance was measured at λ = 420 nm. A standard solution containing 50 g of quercetin in 50 ml distilled water was prepared in a 50 ml measuring flask. A standard curve was also made, and the content of total flavonoid was expressed as mg of quercetin equivalent/gram of extract.

As previously mentioned, eight different extracts were prepared at different variations, as presented in Table 1. Each sample of the nano-sized eucalyptus leaves extract was prepared under high-speed stirring in an Ultra-turrax homogenizer with the following chemical composition: 2% polyethylene glycol, 5% Tween 80, 46.5% Eucalyptus extract and 46.5% water. This composition was determined based on previously performed experiments.

Table 1: Variations of eucalyptus leaves extract prepared

Name of samples	Type of solvent	Speed of homogenization (rpm)
A	Methanol (96%)	No homogenization (control)
B		13,000
C		15,000
D		17,000
E	Ethanol (96%)	No homogenization (control)
F		13,000
G		15,000
H		17,000

In the initial stage, two mixtures, referred to as Mixture 1 and Mixture 2, were prepared. To make Mixture 1, the exact amounts of polyethylene glycol and Tween 80 needed for each sample were mixed and stirred for 10 minutes at 600 rpm. Mixture 2 was prepared from the eucalyptus leaves extract and water with the aforementioned composition under the same conditions with constant stirring. Mixture 1 was then carefully dripped into Mixture 2, still with constant stirring. After the last drop, homogenization was started using an Ultra-turrax homogenizer at each corresponding speed (13,000 rpm, 15,000 rpm and 17,000 rpm) for 10 minutes. The two control samples were mixed without homogenization.

Particle size analysis (PSA) was immediately carried out for each sample of the resulting nano-emulsion. The principle of the PSA test is to measure Brownian motion between particles and the medium (water). Measurements were made under light scattered by a collection of particles. The angle of light scattering is inversely proportional to the size of the particles. The greater the scattering angle, the smaller the particle size.

2.3 Dyeing on cotton and evaluation of dyed fabrics

The dyeing process and the evaluation of dyeing results were carried out in the Laboratory of Textile Physical Chemistry, Politeknik STTT Bandung using the continuous two-dip-two-nip method. The wet pick up (WPU) of the padder was set at 80%. Up to 100 ml of each dyeing solution (solution A to H) was prepared in a saturation bath and the fabric was soaked in the solution for 10 minutes. The fabric was then padded without any additions of other auxiliaries. The fabric was then subjected to the drying process at room temperature. Pre-mordanting with aluminium sulphate and ferro sulphate was carried out to improve the dyeing procedure.

The colours of all dyed fabrics were then evaluated using a Minolta CM-3600d visible light spectrophotometer (Minolta Singapore (Pte), Singapore). The colour depth was expressed in the K/S value obtained from reflectance measurements using the Kubelka-Munk reflectance theory [23], while the colour shades are expressed using L^*, a^* and b^* values. To ensure the accuracy of the data, measurements were made at three different positions of the fabric. In addition, colour fastness to washing of the dyed fabric was tested according to SNI ISO 105-C06-2010 (Textiles – Tests for colour fastness – Part C06: Colour Fastness to Domestic and Commercial Laundering) [24]. To do this test, the sample cloth was covered with cotton and wool (according to sections F01 to F08 of ISO 105-F:1985) on two different sides before being put into a vessel that already contained washing liquor (4 g/l ECE phosphate reference detergent, without an optical brightening agent) and 10 steel marbles. The process was carried out in a Launder-O-meter machine at 40 °C for 45 minutes. The fabric was then rinsed under cold running water and dried. The change in colour of the sample and staining of the adjacent fabrics were evaluated using the grey scale, based on ISO 105-A03. In addition, the colour fastness to rubbing of the dyed fabrics was tested according to SNI ISO 105-X12(E):2016 (Textiles – Tests for colour fastness – Part X12: Colour fastness to rubbing) [25].

2.4 Antibacterial test

Antibacterial tests were carried out on a solution of eucalyptus leaves extract before and after homogenization, and on the dyed fabric. For testing the extract, the well-known Broth or agar dilution method was applied by using agar as a medium for bacterial growth and 0.85 NaCl as a medium for bacterial dilution. The process of making agar was carried out first by mixing 0.13 gram of sodium broth and 0.18 gram of bacteriological agar in an Erlenmeyer flask. A total of 1,000 ml of distilled water was added and the mixture was homogenized. The resulting solution was then covered with aluminium foil and heated using a hot plate at 100 °C with constant stirring at 80 rpm until the solution was clear, and then cooled. On the other hand, the preparation of 0.85% NaCl as the bacterial diluent medium was carried out by homogenizing 8.5 gram of NaCl in 1,000 ml of water. The resulting sodium agar and NaCl solutions were stored in a heat-resistant basket covered tightly with aluminium foil and cotton to prevent the lid from opening during the sterilization process. All tools, including tips, petri dishes and well moulds, as well as materials (sodium agar and NaCl solution) were sterilized in an autoclave at a temperature of 121 °C and pressure of 4 atm for 15 minutes. After cooling, all materials were stored in a refrigerator to keep them sterile.

For the process of inoculating the bacteria, a *Staphylococcus aureus* bacteria pellet was placed in 10 ml of sterile NaCl solution, and then covered with cotton. The work was carried out in a laminar air flow that had been sterilized with 70% ethanol. The solution was then incubated at 37° C for 48 hours and observed to determine whether bulk was formed. Turbidity in the solution indicated that the bacteria was successfully grown and developed. The resulting bacteria solution was stored in a refrigerator to keep them alive.

Finally, and antibacterial test using the agar dilution method was performed. The bacterial solution was diluted with sterile NaCl solution up to six times, which was vortexed for 30 seconds to ensure a homogeneous solution in each dilution process. Next, 1 ml of bacterial and 25 ml of diluted sodium agar solution were placed sequentially on a petri dish, and then homogenized by rotating the dish and left to stand until hard. A well with a sterile mould in the middle of the petri dish was made. Ten microliters of the test sample or the blank was placed in the well. The cup was covered and incubated at 37 °C for 48 hours. Observation was performed to check whether a clear zone formed. The larger the diameter of the clear zone, the better the activity of the antibacterial substance. For antibacterial test on fabric, the ISO 20743-2011 standard was followed using basically the same method used for the extract, only that the sample was in the form of fabric.

3 Results and discussion

3.1 *Phytochemical analysis of the eucalyptus leave extracts*

Phytochemical analysis was conducted on eucalyptus leaves extracts to assess the level of total phenols, tannins and flavonoids, all of which are natural contents that are expected to contribute to the dyeing and antibacterial properties of the extract. Table 2 presents the phytochemical analysis results of the extract.

Table 2: Results of phytochemical analysis of the eucalyptus leaves extract

Eucalyptus leaves extract solution	Concentrations (µg/ml) of		
	tannin	phenol	flavonoid
In 96% ethanol	35.97	232.69	60.12
In 96% methanol	31.68	238.76	63.51

The data in Table 2 show approximately the same amount of tannin, phenol and flavonoid in both extracts (96% ethanol and 96% methanol). This means that in both solvents, the dyeing and antibacterial properties of the extracts are expected to be only very slightly different. Tannin is a complex organic compound comprising phenolic components that contribute to the yellow to brown pigmentation observed. The resulting extract showed a brown hue that confirmed the existence and quantity of total tannins obtained through spectrophotometric analysis with tannic acid as the reference standard. The extract was then subjected to reaction with Folin-Ciocalteu reagent and sodium carbonate until a blue coloration. This change in colour signified a redox reaction where tannins function as reducing agents and Folin-Ciocalteu as oxidizing agents [17]. *Eucalyptus globulus* leaves are already known to contain tannin as a compound that is easily soluble in organic solvents such as methanol, ethanol and acetone. Ethanol and methanol were selected as solvents used in this research because they were easy to obtain and relatively cheaper than other organic solvents, while the maceration process at room temperature was used because the process was easy and it was expected to maintain high levels of leaves extraction yield. In excessive heat, tannin will easily break down into pyrogallol, pyrocatechol and phloroglucinol, causing the loss of its colouring function. Therefore, the maceration process at room temperature was used to maintain the content of tannin in the extract. From the observation during the experiment, a deep brown solution was obtained, indicating the successful extraction of tannin, which acted as a weak acid because of its content of several phenolic OH-groups, indicated by the pH 5.7 of the extract solution. The extraction using methanol and ethanol was intended to dissolve not only tannin, while other important compounds in the Eucalyptus leaves, such as essential oil containing 1,8-cineol, demonstrated antibacterial properties. The 1,8-cineole compound, with its fresh aroma of camphor, demonstrates good bioactivity for some gram-positive and some-gram negative bacteria, as well as anti-fungal, anti-inflammatory and antioxidant properties [4, 12].

The extract also contained phenolic compounds that function as antioxidants [18]. A total phenol analysis was conducted using gallic acid as the standard. Similar to the tannin analysis, the solution turned blue due to redox reactions. A blue colour solution indicated the presence of phenolate ions, which were directly proportional to the phenol content in the solution. Finally, a total flavonoid test was conducted using aluminium chloride as a reagent and quercetin as the standard. Aluminium chloride can form a stable complex with mostly hydroxyl groups presented in flavonoid compounds. The configuration of this stable complex compound was shown by a yellow-coloured solution that was observed during the test. Flavonoids are secondary metabolite compounds that are most often found in plants that function as antioxidants and can be used as antibacterial agents.

3.2 Size of the nano-emulsion

As evident from Table 3, the results of the particle size analysis showed that the target size of the nano-emulsion (in the range of 1–100 nm) for eucalyptus extract was achieved from all the extracts in 96% ethanol homogenized at speeds of 13,000 rpm, 15,000 rpm and 17,000 rpm, which resulted in sizes of 22.84 nm, 52.40 nm and 32.21 nm, respectively. At a speed of 15,000 rpm, the size of the nano-emulsion was slightly higher than the other emulsions. This could be because of the aggregation process of the resulting nanoparticles during the homogenization process that resulted in a slightly larger size [9], although it was still in an acceptable nanosize. This could have occurred when the additional speed stimulated nanoparticles that successfully formed to collide and then reaggregate. At a speed of 17,000 rpm, the higher stirring speed was able to again separate the aggregating nanoparticles, so that the size of the emulsion could still be formed at a slightly lower nanosize of 32.21 nm. Likewise, the results of the nano-emulsion measurements of eucalyptus leaves extract with a 96% methanol solvent showed that nano-size targets were achieved at speeds of 13,000 rpm, 15,000 rpm and 17,000 rpm with sizes of 83.95 nm, 16.85 nm and 64.90 nm, respectively. Here, we can see the opposite trend of results, where the nano-emulsion produced from the homogenization process at a speed of 15,000 rpm demonstrated the smallest size compared to the other two samples. From the test results it can be concluded that the speed of homogenization and the types of solvent were not directly proportional to the reduction in the size of the resulting particles. However, it is noteworthy that the results of this work can be a reliable reference in carrying out similar work in the future because the results presented in this study are those of works that were validated through repeating the exact same method at least once for each process condition. The PSA data of each sample was taken from the average of three different measurements of the same sample, which was then averaged further, taken from the two different samples homogenized under the same condition.

Table 3: Results of the particle size analysis of the eucalyptus leaves extract solutions

Eucalyptus leaves extract solution	Speed of homogenization (rpm)	PSA results	
		Diameter (nm)	Polydispersity index (PDI)
In 96% ethanol	0	153.73	0.192
	13,000	22.84	0.470
	15,000	52.40	0.489
	17,000	32.21	0.685
In 96% methanol	0	1,472.17	0.836
	13,000	83.95	0.350
	15,000	16.85	0.402
	17,000	64.90	0.467

The Polydispersity index (PDI) value from the test results shows a fairly good value, which is below 0.5 for all homogenized solutions. PDI is an index value used to estimate the range of particle size distribution present in a sample. The smaller the PDI value, the more uniform the particle size [26]. From the test results, it can be concluded that the formed nano-emulsion is quite homogeneous.

3.3 Dyeing results

The dyeing of cotton fabrics with the eucalyptus leaves extract may occur because of the interaction between cellulose and the tannin contained in the extract, which also have numerous hydroxyl groups that can interact to form hydrogen bonds with the hydroxyl groups of cellulose, as depicted in Figure 1 [13]. In this case, where the tannin was not isolated, interaction with other polyphenols contained in the extract was also possible. However, from a visual analysis of the dyed fabrics, the colour of tannin was dominant.

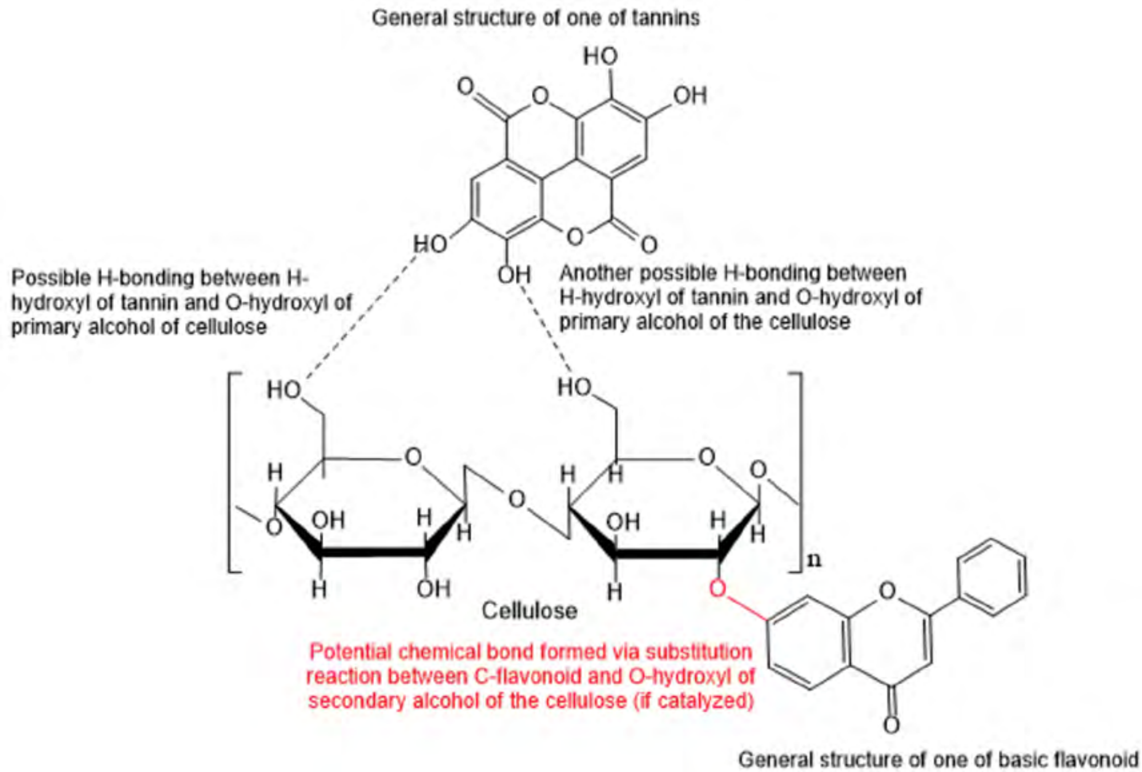
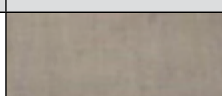
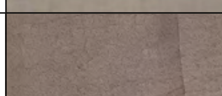
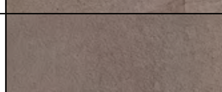
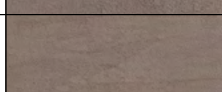
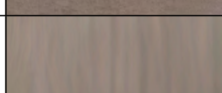
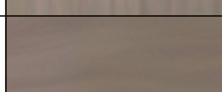
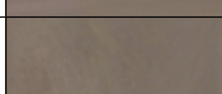
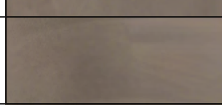


Figure 1: Schematic interaction between tannin and flavonoids and cotton fabric

Potential interactions between tannin and flavonoids contained in the extract and cellulose, as illustrated in Figure 1, shows that at least two possible strong interactions could occur: (i) through a hydrogen bond between the H-hydroxyl of tannin and O-hydroxyl of the primary alcohol of the cellulose; and/or (ii) through a strong covalent bond between the C-flavonoid and O-hydroxyl of the secondary alcohol of the cellulose, which can be formed through a substation reaction mechanism. Of course, the reaction needs to be catalysed. In addition to the two-example mechanism, phenol that was confirmed to be contained in the extract can also create a physical or chemical interaction with the cellulose [27]. Colour measurement results of the dyed fabric using visible-light spectrophotometer and photographed images of the fabric are presented in Table 4. It is evident from the table that the fabric dyed with nano-sized eucalyptus leaves extract in ethanol and methanol, respectively with speed variations of 13,000 and 17,000 rpm, quantitatively demonstrated better penetration of the dyes into the fabric represented by higher K/S values, as seen by a higher colour strength than the other samples. This was consistent with the size of their nano-emulsions. Kinetically, smaller-sized particles can adsorb and diffuse much more easily and quickly into the fabric, and with more particles, which results in higher colour intensity. However, the K/S values of all samples were not significantly different, meaning that the colour difference between each dyed fabric was not visually identified. The K/S value is an important parameter in the study of coloured materials, particularly in the context of the Kubelka-Munk theory, which is used to describe the reflectance and transmittance of diffuse materials, where K represents the absorption coefficient and S represents the scattering coefficient, which both represent how much light is absorbed and scattered respectively per-unit distance. This theory provides a mathematical model to relate the reflectance of a diffusely reflecting sample to its absorption and scattering properties. The K/S value can be derived from reflectance measurements using the formula: $K/S = (1 - R)^2/2R$, where R represents the reflectance of the material. It is also important to explain here that all K/S values were taken from their maximum wavelengths because those wavelengths represent the point of highest absorption, providing critical and consistent information about a material's colour properties and ensuring accuracy in various practical applications. It is widely understood that coloured materials have specific wavelengths based on their colour, known as the maximum wavelength (λ_{max}) of absorption. The K value is highest at λ max because this is where absorption reaches its peak. The K/S ratio at this wavelength thus gives the most significant information about the colour strength of the materials. Taking the K/S value at the maximum wavelengths ensures that the measurement reflects the most intense interaction of light with the material. This also helps in accurately determining the concentration of colorants in a sample, understanding its colour properties, and predicting its behaviour under different lighting conditions. By standardizing the measurement at the maximum wavelength, it becomes easier to compare the colouring efficiency and properties of different samples or batches of the same materials. This is important for consistency in industries such as the textile industry [28].

Table 4: Colour test results of the dyed fabrics (without mordant)

Eucalyptus leaves extract solution	Speed of homogenization (rpm)	Photo of dyed fabrics with eucalyptus leaves extract	Colour test results (measured at maximum wavelength of 430 nm)					
			K/S value	Reflectance (%)	Standard deviation	*L**	*a**	*b**
In 96% ethanol	0		0.870	26.023	0.444	78.64	2.77	14.15
	13,000		0.909	18.107	0.122	60.01	3.18	11.44
	15,000		0.870	26.023	0.444	72.84	0.81	14.41
	17,000		0.887	22.667	0.272	72.70	1.82	13.67
In 96% methanol	0		0.868	26.473	0.359	80.07	2.27	11.98
	13,000		0.888	22.327	0.229	75.28	1.20	12.88
	15,000		0.898	20.453	0.127	65.61	1.00	13.10
	17,000		0.882	23.693	0.206	73.83	1.57	13.14

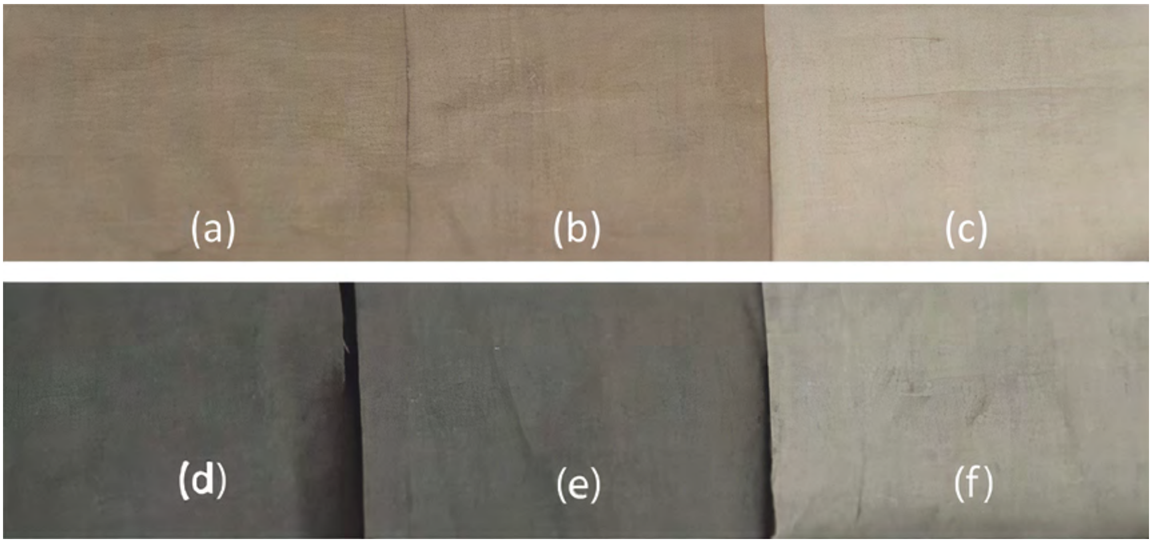


Figure 2: Visual appearance of fabrics dyed used nano-sized eucalyptus leaves extract, mordanted with aluminium sulphate in (a) ethanol at 13,000 rpm, in (b) methanol at 13,000 rpm and in (c) methanol without homogenization; mordanted with ferro sulphate in (d) ethanol at 13,000 rpm, in (e) methanol at 13,000 rpm, and in (f) methanol without homogenization

Moreover, with the repetition of the same measurements on the same sample at five different sites, the levelness of the dyeing results was also analysed, and all samples demonstrated a very good levelness of dyeing, represented by their low standard of deviation value (< 1). Colour difference ($\Delta E_{L^*a^*b^*}$) was not separately calculated here because there were no samples taken as the standard, and the L^*, a^* and b^* values of each sample were found to be significantly different. The value of K/S of each sample was relatively low, showing the pale shade of the dyed fabric. This was confirmed by the high L^* values of all dyed fabrics. It terms of colour shades, it is evident that all samples demonstrated positive a^* and b^* values, meaning that the all-brown coloured fabrics had a strong yellowish shade with sightly reddish colours. The pale shade of the dyed fabric was also the reason that the effect of homogenization speed on colour strength could not be clearly observed. It has been suggested in the other work that the exhaust dyeing method is used with a higher concentration of the dye to achieve a more clearly different colour of the dyed fabric. Mordanting, however, increased the colour strength of the dyed fabrics and shifted the colour shade, as seen by those fabrics mordanted using ferro sulphate ($FeSO_4$). Figure 2 presents some selected images of photographed dyed fabrics that were pre-mordanted with aluminium sulphate ($Al_2(SO_4)_3$) and ferro sulphate ($FeSO_4$).

In addition, Table 5 presents the colour fastness to washing and rubbing of the dyed fabrics. It is evident that the fabrics dyed with nano-sized eucalyptus leaves extract showed slightly better fastness. However, in general, all samples showed very good fastness to washing and rubbing. This was indicated by the grey scale values of staining and the colour change obtained from the fastness test, which varied between 4/5 and 5. The same results can also be observed from the testing of dry and wet rubbing fastness, which also varied between 4/5 and 5. The good colour fastness of the dyed fabrics could be because of the very strong interactions between the nano-sized dyes and because of the very bright and light colour showed by all dyed fabrics, which was confirmed by the high L^* values of all samples, i.e. ranging between 60.01 and 80.07.

Table 5: Colour fastness to washing and rubbing of the dyed fabrics

Dyed fabrics with eucalyptus leaves extract	Speed of homogenization (rpm)	Colour fastness to washing			Colour fastness to rubbing	
		Grey scale for staining on		Grey scale for colour change	Grey scale for staining on dry rubbing cloth	Grey scale for staining on wet rubbing cloth
		cotton	wool			
In 96% ethanol	0	4/5	4/5	4/5	5	4/5
	13,000	5	5	5	5	5
	15,000	5	4/5	5	5	5
	17,000	4/5	4/5	4/5	5	5
In 96% methanol	0	4/5	4/5	4/5	5	4/5
	13,000	4/5	4/5	4/5	5	4/5
	15,000	5	5	5	5	5
	17,000	5	5	5	5	4/5

3.4 Antibacterial properties

Antibacterial tests were carried out to check the antibacterial properties of the *Eucalyptus globulus* in the form of extract and the dyed fabric. The results are presented in Figures 3 and 4. The test results showed that in a solution of eucalyptus leaves extract with 96% ethanol and methanol solvents, shown as B and C in the Figure 3, respectively, clear zones were formed, at distances of 1.76 cm and 1.96 cm, respectively. This demonstrated that the antibacterial substance made from the eucalyptus leaves extract was successfully extracted with both solvents, and the ability to inhibit the bacteria was slightly higher in the extract with methanol solvent than in the extract with ethanol solvent. According to Rahayu [29], the inhibition zone activities of antimicrobials are classified into four categories: weak activity (<5 mm), medium activity (5–10 mm), strong activity (> 10–20 mm), very strong activity (> 20–30 mm). Antimicrobial inhibitory activity is expressed based on the clear zone generated around the well. The diameter of the bacterial growth inhibition zone is measured in mm. Thus, the antibacterial activity of the *Eucalyptus globulus* extract in 96% ethanol and methanol solvents were both strong.

The homogenization process using an Ultra-turrax homogenizer on the extracts provided an even better antibacterial effect of the formed *Eucalyptus globulus* nano-emulsions. This can be seen by the results presented by images D and E in Figure 3, which shows nano-sized *Eucalyptus globulus* in the ethanol and methanol, where both demonstrated very strong antibacterial activity with inhibition zones of 2.34 cm (23.4 mm) and 2.36 dm (23.6 mm), respectively. The results indicated that the nano-sized particles in the nano-emulsion demonstrated higher antibacterial activity than those without homogenization or in a micro-sized emulsion. This confirmed that the nano-sized emulsions could diffuse very well on agar that has been inoculated with bacteria, thus improving the antibacterial activity [26]. All extracts measured in this study showed strong to very strong antibacterial activity, while the distance of their inhibition zones is still under the positive control of *Eucalyptus globulus* essential oil (sample A). These results are reasonable because in essential oil, the eucalyptus globulus content could reach maximum purity. On the other hand, under the extraction process in 96% methanol or ethanol, there might be some impurities that cannot be isolated or separated from the extract, thus decreasing the overall strength of the antibacterial activity of the extracts.

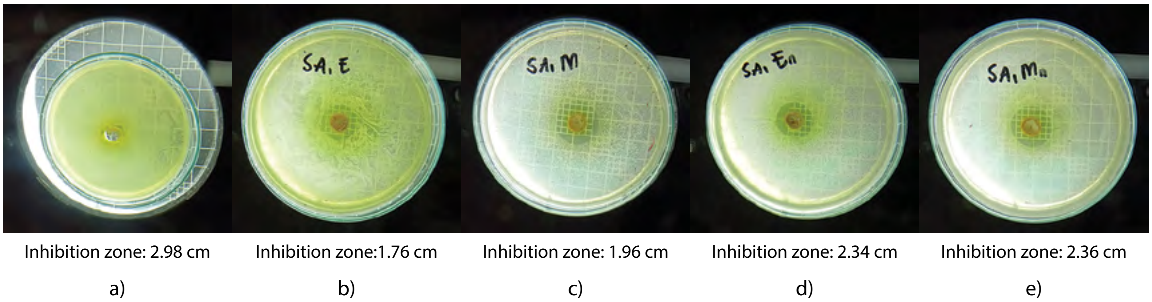


Figure 3: Antibacterial properties of the eucalyptus leaves extracts: a) positive control of Eucalyptus globulus essential oil, b) in 96% ethanol, c) in 96% methanol, d) homogenized at 13,000 rpm in 96% ethanol, and e) homogenized at 15,000 rpm in 96% methanol

An antibacterial test on fabric dyed with nano-sized and normal size eucalyptus leaves extract was carried out using the same method as those on the extract solutions, but referencing SNI ISO 20743-2011 (SNI ISO 20743-2011 – Antibacterial) [30] in the case of samples on the dyed fabrics. The aim of the test was to confirm whether after passing the dyeing process, the antibacterial properties of the *Eucalyptus globulus* in the dyed fabrics still survived. Images of the test results are presented in Figure 4. It is evident from Figure 4 that all dyed fabrics showed higher antibacterial ability compared to the eucalyptus leaves extract solutions. These are shown by the clear zone formed in all images with inhibition zones at a greater distance than those in the extract solutions.

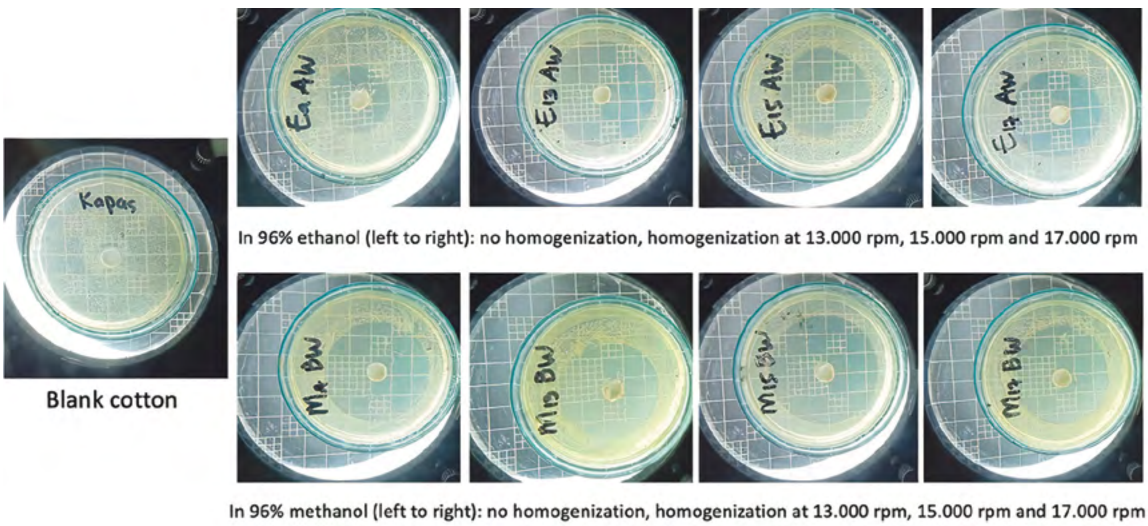


Figure 4: Antibacterial properties of the dyed fabrics

For further clarity, Table 6 presents the quantitative results of the tests. The measurements on the dyed fabrics were taken at three positions, and the average distance of the inhibition zones was calculated. It is evident from the data that all dyed fabrics that were dyed by normal or nano-sized *Eucalyptus globulus* extract demonstrated very strong antibacterial activity. In contrast, the blank cotton fabric showed very weak antibacterial activity. These results confirmed that dyeing cotton fabric with *Eucalyptus globulus* extracts had a significant effect on the formation antibacterial properties. The stages of dipping and nipping of the fabric during the dyeing process did not decrease or nullify the antibacterial effect. On the other hand, that effect increased significantly.

Table 6: Inhibition zones of the dyed fabrics

Fabrics dyed by extracts	Speed of homogenization (rpm)	Distance of inhibition zones (mm) from three measurements	
		Average	Standard deviation
Blank/standard cotton	-	0.33	0.47
In 96% ethanol	0	38.33	1.25
	13,000	45.00	0.82
	15,000	40.33	0.47
	17,000	43.00	0.00
In 96% methanol	0	40.00	0.82
	13,000	45.33	0.47
	15,000	42.00	0.82
	17,000	44.33	0.47

Similar to the results of the test on the extract solutions, the antibacterial test on fabric dyed with nano-sized eucalyptus leaves extract showed a larger clear zone than those dyed with the normal size of the Eucalyptus extract. Distribution of the nano-sized eucalyptus particles in the fabric was more compact and thus gave a much higher surface area or surface activity. Therefore, much higher amount of the particle could penetrate the fabric, and result in higher antibacterial activity. Moreover, the size does matter for the case on a solid surface such as fabric. The smaller size distribution on the surface of the fabric could also physically prevent penetration of the bacteria into the fabric because the size of the pore between particles might be much smaller than the size of the bacteria itself. This phenomenon might occur apart from the chemical effect of the antibacterial properties coming from the *Eucalyptus globulus* extract used in the dyeing process. To confirm the durability of antibacterial properties, two fabrics dyed with nano-sized eucalyptus leaves extract homogenized in 96% ethanol and methanol at 13,000 rpm were washed according to the ISO-6330:2012 standard, IDT (Textiles – Domestic washing and drying procedures). The antibacterial activity of the washed fabrics was then tested. The results showed that there was no significant decrease in antibacterial activity after washing. As indicated by the average distance of inhibition zones of the washed fabrics, the antibacterial activity of the two selected fabrics was maintained. The decreases in the inhibition zone distance were only 0.87 mm or 1.93% (from 45.0 mm to 44.13 mm) and 1.36 mm or 3.00% (from 45.33 mm to 43.97 mm) for fabrics dyed with extract homogenized in ethanol and methanol, respectively. Measurement results are presented in Table 7.

Table 7: Comparison of antibacterial activity of selected dyed fabrics before and after domestic washing and drying

Fabrics dyed by extracts		Distance of inhibition zones (mm) from 3 times measurements	
		Average	Standard deviation
In 96% ethanol at 13,000 rpm	Before washing	45.00	0.82
	After washing	44.13	0.25
Difference		**0.87 (1.93%)**	
In 96% methanol at 13,000 rpm	Before washing	45.33	0.47
	After washing	43.97	1.81
Difference		**1.36 (3.00%)**	

In general, the antibacterial activity of the fabrics was still very strong (> 20-30 mm) after the domestic washing and drying treatment. This confirms that the polyphenols contained in the extract, i.e. tannin, phenol and flavonoid, played an important role in providing a significant antibacterial activity of the dyed fabrics. The durability test also showed that strong interaction between the polyphenols and cotton fabric had occurred. This is also confirmed by the good-very good washing fastness of the dyed fabrics to washing and rubbing, as presented in Table 5. From the dyeing results, it can also be concluded that antibacterial activity demonstrated by the nano-sized eucalyptus leaves extract was more significant than its dyeability because the visual appearance of the dyed fabrics only showed the typical colour of most natural dyes. They did not demonstrate a distinctive shade or a more intense colour.

4 Conclusion

Nano-sized *Eucalyptus globulus* extracted in 96% ethanol and methanol solvents, using Tween 80 and polyethylene glycol surfactants, were successfully made through homogenization at various speeds of 13,000 rpm, 15,000 rpm, and 17,000 rpm in this research. The content of tannins, phenols and flavonoids in the extract was determined. A significant decrease in the size of Eucalyptus particles in the extract homogenized at the aforementioned speeds was observed from the results of size analysis using a PSA (particle size analyser). The dyeing of cotton fabric with the extracts using the two dips-two nips method showed a pale brown shade at the maximum wavelength of 430 nm. All dyed fabrics showed good and very good fastness to washing and rubbing. The antibacterial activity of the *Eucalyptus globulus* leaves extracts were all strong and very strong, which was demonstrated very well by their inhibition effect. On the other hand, the dyeing of cotton fabric with the extracts demonstrated the typical colour of most natural dyes. A typical phenomenon discovered was that nano-sized Eucalyptus particles in the extract demonstrated higher antibacterial activity than those in normal size. Moreover, the antibacterial activity of dyed fabric was significantly higher than those in the form of extract solutions.

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Development of Automatic Balancing Application for Fashion Company Using Artificial Intelligence

Razvoj aplikacije za samodejno uravnoteženje procesov v modnem podjetju s pomočjo umetne inteligence

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Abstract

Industrial companies aim to minimise production costs and improve product quality by analysing work organisation levels. Workshop scheduling and line balancing are essential in realising production plans, particularly in the fashion industry. Balancing systems must optimise precise criteria while sticking to constraints. Preserving balance needs precise parameters that align theoretical and practical production results. Manual methods overlook the balancing process, where managers rely on experience to prove balance and adjust parameters as needed. This article presents a creative automatic balancing application for fashion companies, leveraging artificial intelligence's (AI) power. It focuses on utilising ant colony algorithms for optimal balancing. The results show the significance of these algorithms in attaining optimal balancing in production systems. The article highlights outstanding balancing results achieved through this approach, providing alignment with detailed criteria and constraints. The algorithm reliably distributes tasks among operators, improving overall productivity. Therefore, ant colony algorithms are perfect for manufacturers pursuing cost reduction, improved product quality and facilitated production processes. This article introduces an AI-based automatic balancing application for fashion companies. The ant colony algorithms achieve optimal balancing, improve inventory management and enhance productivity.
Keywords: automatic balancing, fashion company, artificial intelligence, ant colony method

Izvleček

Industrijska podjetja si prizadevajo zmanjšati proizvodne stroške in izboljšati kakovost izdelkov z analiziranjem različnih ravni organizacije dela. Načrtovanje obrata in uravnoteženje proizvodnih linij sta bistvena pri uresničevanju proizvodnih načrtov, še posebno v modni industriji. Sistemi za uravnoteženje morajo optimizirati natančna merila in istočasno upoštevati omejitve. Za ohranjanje ravnotežja so potrebni natančni parametri, ki usklajujejo teoretične in praktične rezultate proizvodnje. Pri ročnih metodah se lahko spregleda postopek uravnoteženja, saj se za vzpostavljanje ravnovesja vodje zanašajo na dosedanje izkušnje in po potrebi prilagajajo posamezne parametre.

V članku je predstavljena kreativna aplikacija za samodejno uravnoteženje za modna podjetja. Aplikacija temelji na izkoriščanju potenciala umetne inteligence in se osredotoča na uporabo algoritmov kolonije mravelj za optimalno uravnoteženje. Rezultati prikazujejo pomen teh algoritmov pri doseganju optimalnega uravnoteženja v proizvodnih sistemih. Članek izpostavlja izjemne rezultate uravnoteženja, dosežene z omenjenim pristopom, ter zagotavlja uskladitev s podrobnimi merili in omejitvami. Algoritem zanesljivo porazdeli naloge med deležnike in tako izboljša splošno produktivnost. Algoritmi kolonije mravelj so zato odlična metoda za proizvajalce, ki si prizadevajo zmanjšati stroške, izboljšati kakovost izdelkov in poenostaviti proizvodne procese. V članku je predstavljena aplikacija za samodejno uravnoteženje za modna podjetja, ki temelji na umetni inteligenci. Algoritmi kolonije mravelj dosežejo optimalno uravnoteženje, izboljšajo upravljanje zalog in povečajo produktivnost.

Ključne besede: samodejno uravnoteženje, modno podjetje, umetna inteligenca, metoda kolonije mravelj

1 Introduction

Research and development in the textile and fashion industry are compelled by the demand for industrialised countries to protect themselves against competition via the utilisation of skilled and cost-effective labour [1–3]. This industry's critical objectives are improving product quality, reducing manufacturing time and enhancing delivery times [4]. However, these objectives entail different constraints, requiring companies to assume proper procedures and means to sweeten organisational efficiency, offer better customer service at a lower cost and ensure a smooth flow of goods within their production systems [5]. Balancing clothing chains is vital for optimising workflow in the textile clothing industry [6]. It concerns distributing work equitably among further operators, minimising breaks between tasks, and reducing work in progress [7, 8].

Guo et al. [9] highlight that decision-making problems in the industry, such as apparel design, production scheduling and sales forecasting, can be complicated and difficult. The complexity of the industrial problem often restricts the use of exact methods to find an optimal solution due to the demand for adaptable strategies that can adjust detailed constraints [10]. An adequate artificial intelligence technique, especially Genetic Algorithm (GA), was blended with "earliness" and "tardiness" production scheduling and planning methods to schedule the clothing manufacturing process [11]. Metaheuristics have occurred as a selected resolution strategy, presenting adjustable solutions. For example, in their study, Chan et al. [12] introduced a new approach that employs genetic algorithms to attack the assembly line balancing problem in the clothing industry.

In other studies [13], the authors discuss the significance of comprehending consumer responses to new technologies in the fashion industry, specifically concerning the growing integration of fashion and digital innovations. In recent years, there has been a growing curiosity about involving artificial intelligence (AI) techniques in the textile industry. Some researchers [14] explore using AI, including machine learning and neural networking, to improve operational processes in the textile industry. The authors examine how computer algorithms and AI-based methods have improved efficiency and automation, mainly in yarn manufacturing, fabric manufacture and coloration. According to [15], some studies underline the vast utilisation of artificial intelligence in operational planning within the textile production domain. The researchers highlight the value of operational planning in the production process and study various artificial intelligence strategies and algorithms, including the search method, ant algorithm [16], genetic algorithms and neural networks [17], which can be virtually operated in textile production planning. Others [18] find that AI has notable possibilities for different applications in retail, mainly in areas where future forecasting is required, such as marketing and replenishment.

The heuristic methods provide proximate to optimal solutions for complex combinatorial optimisation problems [19]. While most heuristic methods are designed for distinctive problem types, metaheuristics, such as simulated annealing [20], tabu search [21] and genetic algorithms [22], can adjust to different types of issues, including combinatorial and continuous problems. With the help of these metaheuristics, we can now suggest approximate solutions for larger-scale classical optimisation problems and applications that were previously infeasible. There has been a growing curiosity in metaheuristics within operations research and artificial intelligence [23].

The ant colony method carries a splendid reputation in the context of problem-solving within the textile industry, particularly when handling the challenge of balancing clothing lines [24]. This method has confirmed reliability in acquiring optimal solutions for such complex problems. Furthermore, the ant colony method is robust in dealing with large-scale optimisation problems, enabling it to promptly provide approximate solutions [25].

This research paper aimed to develop a metaheuristic approach to address the specific issue of balancing clothing lines and optimise the workload distribution to minimise the number of workers experiencing load imbalances. In this context, we suggest developing balancing software using the ant colony method to consider all the appropriate parameters discovered in various workshop stages.

2 Materials and methods

2.1 Materials

We opted to utilise VB.NET 2015 as the programming language for developing this application during the study. To support the development process, we relied on a computer with this configuration:

- processor: Intel(R) Core(TM) i7-9750H CPU @ 2.60GHz 2.60 GHz,
- installed RAM: 16.0 GB (15.8 GB usable),
- system type: 64-bit operating system, x64 based processor.

2.2 Description of balancing method

2.2.1 Purpose of balancing

Balancing aims to distribute the workload among all workers participating in the product assembly process based on a standard time allocation known as the fragmentation base. Balancing positions concerns reaching an optimal distribution of tasks, considering factors such as worker load, saturation, number and pace at each position.

2.2.2 Balancing table description

The balancing table is a tool that enables the fair distribution of working time for an article across different workstations.

Fragmentation Base (FB)

To calculate the fragmentation, we can use either equation 1 or 2.

$$\mathrm{FB} = \frac{\mathrm{WV}}{\mathrm{NO}} \qquad (1)$$

$$\mathrm{FB} = \frac{T_{pd}}{P_d} \qquad (2),$$

where **WV** is work value – it is the total time required for the production line, **NO** is number of operators – it indicates the number of operators needed, $\mathbf{T_{pd}}$ is time per day – it represents the daily presence time of a worker at a specific station, and $\mathbf{P_d}$ is production per day – it signifies the daily production output at a particular position.

Pace (P_i)

The pace is a result of the combined action of three factors, i.e. speed, precision and method.

Load (L)

The sum of the times denotes the work. The load of each position should be equal to the fragmentation base.

Workforce (WF)

The workforce refers to the number of operators per set. To calculate the workforce at performance equal to 100% or different levels, we use equations 3 and 4.

$$\mathrm{WF}(100\%) = \frac{\mathrm{WV} \times \mathrm{Pd}}{\text{Presence hours}} \tag{3}$$

$$\mathrm{WF}(\mathrm{P}\%) = \frac{\mathrm{WF}(100\%)}{\mathrm{P}\%} \times 100 \tag{4}$$

where WV is work value, Pd is production per day, P% is performance of operator, WF (100%) is the ideal value of workforce with performance of operators considered to be 100% and WF (P%) is workforce taking into account the performance of operators.

Work potential (WP)

The work potential is defined as the time required for an operator to complete their task at maximum efficiency and productivity. It is represented by equation 5.

$$\mathrm{WP} = \frac{\mathrm{FB} \times P_i}{100} \tag{5}$$

where P_i is individual pace of one operator and FB is fragmentation base.

Saturation (S)

Saturation refers to the state of a station or position within a system. It can be calculated using equation 6.

$$\mathrm{S} = \frac{\mathrm{L}}{\mathrm{WP}} \times 100 \tag{6}$$

where L is load and WP is work potential.

2.3 Ant colony method

2.3.1 Presentation of method

In response to the challenge of poor balancing in clothing workshops, we have developed a metaheuristic approach that is highly adaptable to overcome these constraints. Our solution focuses on achieving a fair distribution of tasks among workers, considering various parameters such as their performance, paces, available machine park and other factors contributing to a well-balanced workflow. We have utilised the ant colony method, which is modelled below in Figure 1.

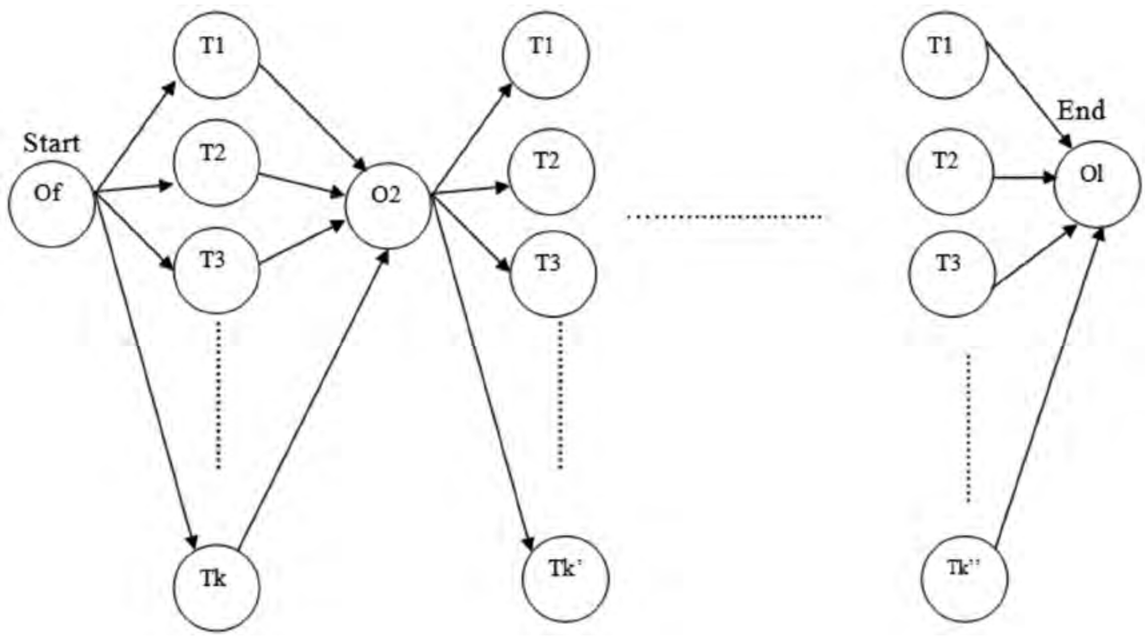

Figure 1: Representation of paths travelled by each ant

2.3.2 Adaptation of balancing technique and ant colony method

In this section, we study the adaptation of the ant colony method as a heuristic approach to solve the balancing problem. In particular, we employ the optimisation algorithm known as Ant Colony Optimization (ACO). This algorithm uses ant agents that traverse a graph while searching for the minimum path. During their exploration, the ants deposit pheromone quantities on the graph's edges, reflecting their experience with the problem. In the program, the heuristic criteria are represented by the matrix $[H_{i,j}]$ and the pheromone trails are presented by the matrix $[\tau_{i,j}]$.

Then, from the trace matrix $[\tau_{i,j}]$ and the heuristic matrix $[H_{i,j}]$, the value $V_{i,j}$, which refers to pheromones, can be calculated through equation 7:

$$V_{ij} = [\tau_{ij}]^{\alpha} \times \left[{}^{1}/_{H_{ij}}\right]^{\beta} \tag{7}$$

The parameters α and β make it possible to adjust the contribution of the two types of global (pheromone trail) and local (visibility) information, respectively.

The method can be explained below:

Initialisation

- T_0 refers to the quantity of elemental pheromones.
- We initialise the trace table with $[\tau_{i,j}] = T_0$.
- We randomly assign the starting operators for the ants.

Couple's choice

We choose among candidate pairs j the one which maximises the function F presented in the following equation 8.

$$F = Max\left({}^{[\tau_{i,j}]^{\alpha}}/_{[H_{i,j}]^{\beta}} \right) \tag{8}$$

The balancing by ant colonies can be summarised by the following flowchart presented in Figure 2.

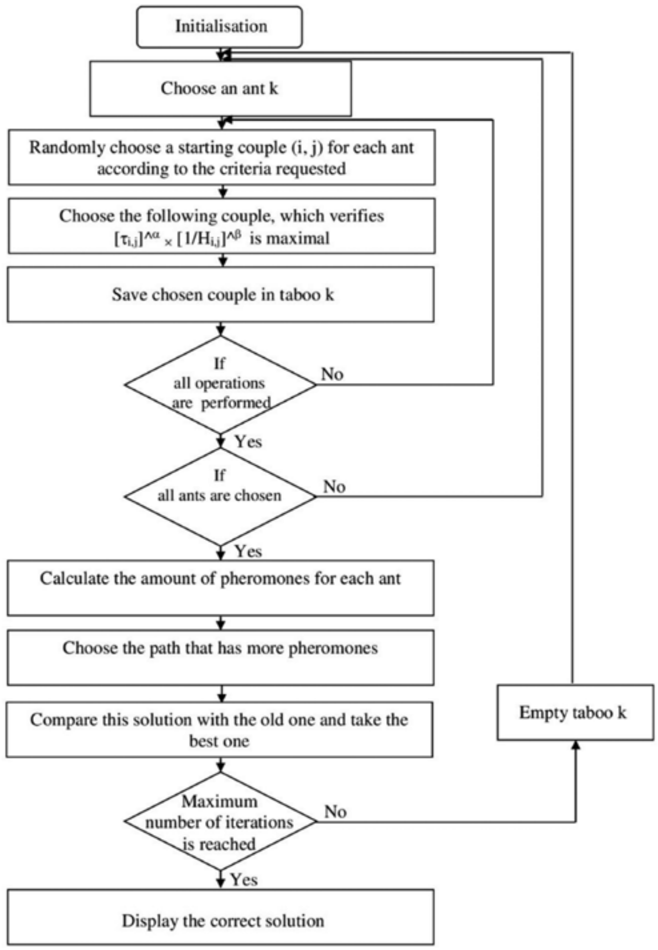

Figure 2: Structure of ACO algorithm

The flowchart in Figure 2 summarises the steps in applying the ant colony method to acquire a balanced distribution of tasks among operators.

3 Results

3.1 Presentation of adopted algorithm

The trace matrix is set initially to a constant value and as the number of iterations (cycles) increases, the number of equal values in the trace matrix decreases. Figure 3 illustrates the flowchart explaining this process.

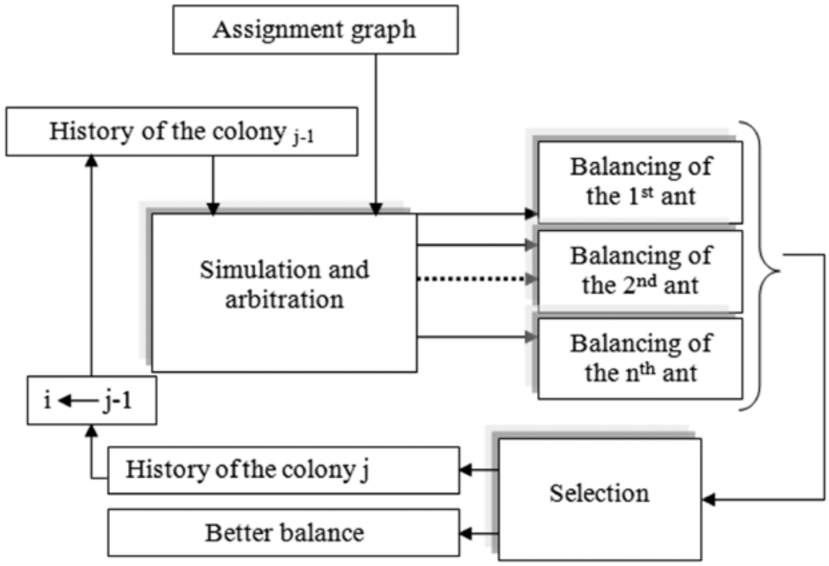

Figure 3: Synoptic of algorithm and memorisation of history of colony

The selection of operations is conducted probabilistically, taking into account several parameters, including:

- ***Quantity of pheromones deposited***: The amount of pheromones deposited between two pairs, such as [Operator (i), Task (j)] and [Operator (i+1), Task (j+1)], plays a critical role in the selection process. This information helps determine which pair [Operator (i+1), Task (j+1)] should be selected to access the following pair [Operator (i), Task (j)].
- ***Internal memory (taboo list)***: Each ant carries an individual memory or taboo list of the pairs it has already visited during a cycle. This memory prevents ants from constructing erroneous solutions by revisiting the same pairs. It helps determine the sequence of pairs that the ant k should visit to complete its process after the (i, j) pair.

3.2 Practical improvement of algorithm

3.2.1 Choice of optimal solution

This method presents a procedure that incapacitates operators who are unable to take a particular type of machine. The role of this method is to memorise the solution based on the following principle:

If the new solution generated by ant k during the last cycle is better than the one currently in memory, the new solution is stored. Otherwise, the memorised solution remains the same.

3.2.2 Orientation of ant in case of multiple solutions

The presence of identical solutions can introduce challenges and potential errors in the balancing process. When faced with equal heuristic values for multiple pairs of (Operator, Task), the algorithm may resort to random selection, which is only sometimes optimal. This disturbance can impact the balancing results in several ways:

- ***Incomplete assignment of operations***: When operations are assigned to only one part of the time, it can lead to an unbalanced workload for the operators. Some operators may be overloaded with tasks, while others may have idle time, resulting in inefficiencies and suboptimal utilisation of resources.
- ***Operations not affected at the balancing table***: Operations with very short execution times may need more attention during the balancing process. As a result, these operations may need to be appropriately assigned, leading to inefficiencies and potential bottlenecks in the workflow.

- **Underutilised operators:** If the balancing algorithm fails to load operators with tasks fully, it can result in underutilised capacities. This system can lead to idle time for operators and decreased overall productivity.
- ***Assignment of incompatible operations***: In some cases, the algorithm may erroneously assign multiple operations performed with machines of different types to a single operator. This choice is impractical and can result in operational constraints and potential conflicts during the execution of tasks.

3.2.3 Proposed strategies for resolving problem of identical solutions in balancing assignments

Prioritise operators with low versatility

Enabling operators with low versatility (those who handle a single type of machine) can help mitigate the risk of solution divergence when faced with identical heuristic values. The following procedure is proposed:

- if $H_{i,j} > H_{i+1,j}$ choose $H_{i+1,j}$.
- if $H_{i,j} = H_{i+1,j}$ select the operator who handles a smaller number of machines.
- if the two operators have the same versatility, the choice will be random.

Note: If the first operator assignment is accomplished randomly, the proposed hypothesis in this research paper cannot be enforced.

Assign operators based on machine type

When there is equality in heuristic values, consider assigning operators according to the type of machine. This procedure tests if the operation assigned to the operator during loading matches the machine type of the operation that needs to be added in case of incomplete load.

3.3 Application example

To illustrate the application of the approach, let us consider a simplified model with three operations and three operators for a single ant in a single cycle. We will refer to Table 1 for details. Assuming a fragmentation base of 58 and a tolerance interval of 10%, the objective is to assign operations to operators in a balanced and optimised manner.

Table 1: Example operations and operators assignment

Operation	Machine	Time (cmin)
O1	M1	43
O2	M1	22
O3	M2	108

The following two tables represent the trace matrix (Table 2) and the heuristic matrix (Table 3). Each table is structured with operations (O) and workers (W) as follows:

Table 2: Trace matrix

	O1_W1	O1_W2	O1_W3	O2_W1	O2_W2	O2_W3	O3_W1	O3_W2	O3_W3
O1_W1	_	1	1	1	1	1	1	1	1
O1_W2	1	_	1	1	1	1	1	1	1
O1_W3	1	1	_	1	1	1	1	1	1
O2_W1	1	1	1	_	1	1	1	1	1
O2_W2	1	1	1	1	_	1	1	1	1
O2_W3	1	1	1	1	1	_	1	1	1
O3_W1	1	1	1	1	1	1	_	1	1
O3_W2	1	1	1	1	1	1	1	_	1
O3_W3	1	1	1	1	1	1	1	1	_

Table 3: Heuristic matrix

	O1_W1	O1_W2	O1_W3	O2_W1	O2_W2	O2_W3	O3_W1	O3_W2	O3_W3
O1_W1	0	0.9	1.1	0.51	0.46	0.56	2.9	2.64	3.22
O1_W2	1.1	0	1.22	0.56	0.51	0.62	3.2	2.91	3.55
O1_W3	0.9	0.81	0	0.46	0.41	0.51	2.62	2.38	2.9
O2_W1	1.95	1.77	2.16	0	0.9	1.1	5.68	5.16	6.3
O2_W2	2.15	1.95	2.38	1.1	0	1.22	6.25	5.68	6.94
O2_W3	1.76	1.59	1.95	0.9	0.81	0	5.12	4.65	5.68
O3_W1	0.34	0.31	0.38	0.17	0.16	0.19	0	0.9	1.11
O3_W2	0.37	0.34	0.41	0.19	0.17	0.21	1.1	0	1.22
O3_W3	0.3	0.28	0.34	0.15	0.14	0.17	0.9	0.81	0

In the given example presented in Table 3, we have a scheduling problem where we need to calculate the heuristic value based on the real time (Tr_work) of two workers performing an operation that has a specified operation time. The unit of time used was the centiminutes (cmin), which are hundredths of a minute.

Let us consider the following information:

Operation time (l) = 43 cmin,

Pace of Worker 1 = 100,

Pace of Worker 2 = 110.

To calculate the real time (Tr_work) of each worker, we can use equation 9:

$$\text{Tr\_work} = \frac{\text{Operation time}}{\textit{Individual Pace}} \times 100 \tag{9}$$

For Worker 1:

Tr_work 1 = (43/100) × 100 = 43 cmin

For Worker 2:

Tr_work 2 = (43/110) × 100 = 39.09 cmin

To calculate the heuristic value, we can use equation 10:

$$\text{Heuristic} = \frac{\text{Tr\_work1}}{\text{Tr\_work 2}} \tag{10}$$

Heuristic = 43/39.09 = 1.09

The heuristic value provides a measure of comparison between the real times of Worker 1 and Worker 2. A value greater than 1 indicates that Worker 1 is slower in completing the operation compared to Worker 2, while a value lower than 1 indicates that Operator 1 is faster.

In the next step, we provide a list of machines each worker can operate to assist the program in making accurate calculations based on worker capabilities. This information is presented in Table 4.

Table 4: Versatility of workers

Worker 1	Worker 2	Worker 3
Machine 1	Machine 1	Machine 1
Machine 2	Machine 2	Machine 3
Machine 3		
...	...	...

Based on the heuristic matrix and the system of choice we have described, each cycle will be presented according to the path deposited by the ant. In the current case, the best choice was highlighted by formatting the cell with a grey background and bold text as presented in Table 5.

Table 5: Assignment of workers according to heuristic matrix

	O1_W1	O1_W2	O1_W3	O2_W1	O2_W2	O2_W3	O3_W1	O3_W2	O3_W3
O1_W1	0	0.9	1.1	0.51	0.46	0.56	2.9	2.64	3.22
O1_W2	1.1	0	1.22	0.56	0.51	0.62	3.2	2.91	3.55
O1_W3	0.9	0.81	0	0.46	0.41	**0.51**	2.62	2.38	2.9
O2_W1	1.95	1.77	2.16	0	0.9	1.1	5.68	5.16	6.3
O2_W2	2.15	1.95	2.38	1.1	0	1.22	6.25	5.68	6.94
O2_W3	1.76	1.59	1.95	0.9	0.81	0	**5.12**	4.65	5.68
O3_W1	0.34	0.31	0.38	0.17	0.16	0.19	0	**0.9**	1.11
O3_W2	0.37	0.34	0.41	0.19	0.17	0.21	**1.1**	**0**	1.22
O3_W3	0.3	0.28	0.34	0.15	0.14	0.17	0.9	0.81	0

The balancing table (Table 6) shows the final results of the calculation system regarding different balancing parameters. This table showcases the optimised assignments of operators to machines based on the balancing criteria incorporated into the system.

Table 6: Balancing table

Operation	Machine	Workers	*Worker 3*	*Worker 1*	*Worker 2*
		Pace	90	100	110
		Time (cmin)			
OP1	M1	43	43		
OP2	M1	22	9.2	12.8	
OP3	M2	108		44.2	63.8
		Potential	52.2	58	63.8
		Workload	52.2	57	63.8
		Saturation	1	0.98	1

After randomly assigning the first operator, our program will reach the heuristic calculation. Other operators will be assigned according to the most extensive value $V_{i,j}$ (the smallest value of $H_{i,j}$).

The elaboration of balancing using the ant colony method is based on the trace left by each ant. Indeed, each time an assignment of operators is performed, the values corresponding to the arcs in the trace matrix are increased. The trace is of two types, i.e. local trace and global trace. The local trace corresponds to all the balancing possibilities carried out. The global trace is specific to the best balancing, i.e. the path that minimises the number of operators having an imbalance in their loads and maximises the number of operators satisfying the balancing objective. As the number of iterations increases, the solution will converge to an optimum.

4 Discussion

To consider the balancing result, there are specific criteria and principles recapped.

4.1 Criteria and principles

Identical time for each position

The primary criterion for judging the balancing result is to give each position or workstation an identical time, indicating a balanced workload distribution.

Placing busiest workstations at the end

It is suggested to place the busiest workstations at the end of the production chain. This arrangement helps minimise production stoppages since the busier workstations are less likely to cause bottlenecks or delays in the workflow.

Minimizing machines assigned to each operator
Another principle is assigning the fewest possible machines to each operator. This process ensures that the workload is distributed evenly among the operators and avoids overburdening any individual operator.

Right operator in right job
Assigning the right operator to the right job is emphasised as a principle. This means matching operators with tasks that align with their skills, expertise or qualifications. By doing so, the efficiency and effectiveness of the workforce can be maximised.

These principles aim to ensure a balanced and efficient workload distribution, minimise production stoppages, optimise resource allocation and enhance overall productivity.

Study of balancing success rate
To accurately evaluate the study's balancing result, a value can be calculated to provide a comprehensive assessment. This value is determined based on the saturation levels of each operator, indicating how close they are to reaching 100% utilisation or how far they are from it. The equation for calculating this value involves considering the saturation values for all operators and taking the average. The saturation value of an operator represents the extent to which their assigned workload approaches maximum capacity.

After conducting numerous tests and examples, we have adopted the following parameters for our calculations:

- runway intensity parameter: $\alpha = 0.8$,
- visibility parameter: $\beta = 0.9$,
- number of ants = number of operators available to perform the first task.

Figure 4 showcases the evaluation of our program by illustrating the evolution of the balancing value over iterations. The x-axis represents the number of iterations or cycles completed by the algorithm, while the y-axis denotes the corresponding balancing value attained at each iteration.

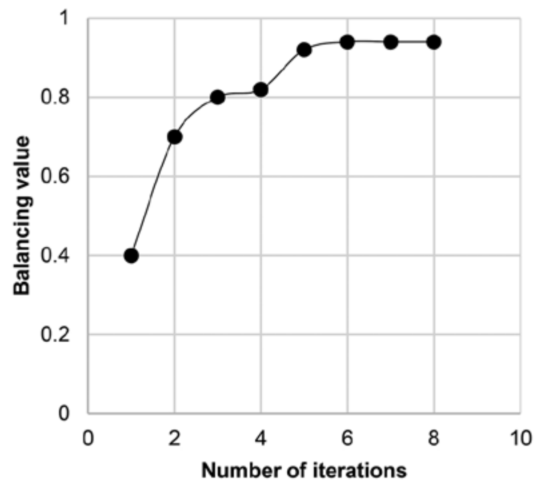

Figure 4: Evolution of balancing value over iterations

In Figure 4, it can be observed that following the implementation of algorithm improvements, there is a clear and significant improvement in the balancing result. As the algorithm iterates through several cycles, the balancing outcome reaches a point of stability and remains constant thereafter.

4.3 Industrial example

In this part, we present an industrial example of a long-sleeve T-shirt for women with lace (Figure 5) in order to explain how our developed program can effectively address and solve problems of balancing.

For this case, we present all the operations of the T- shirt in Table 7.

Figure 5: Long sleeve T-shirt for women with lace

Table 7: List of operations

N°	Operation	Machine	Time(cmin)
1	Stitch the lace at the front	3-thread overlock	120
2	Stitch the lace at the front neckline	3-thread overlock	60
3	Stitch the lace at the back neckline	3-thread overlock	60
4	Stitch the lace at the sleeves	3-thread overlock	45
5	Close side	4-thread overlock	50
6	Roll up the sleeves	4-thread overlock	40
7	Topstitch armholes	lockstitch machine	45
8	Low hem	3-thread overlock	40
9	Peeling	Manual	18
10	Control	Manual	33
11	Ironing	Manual	30
12	Super control	Manual	23
13	Packaging	Manual	33

In our case, we have 10 workers in the workshop with diverse skills, abilities and levels of versatility. The specific details regarding their skills and versatility are presented in Table 8.

Table 8: Versatility of workers/pace

Worker	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Pace	95	100	100	90	110	110	100	100	100	90
Machine/operation										
3-thread overlock		✓	✓	✓	✓		✓			✓
4-thread overlock			✓	✓					✓	✓
Lockstitch machine	✓		✓							
Manual/peeling	✓						✓	✓		
Manual/control							✓	v		
Manual/ironing						✓		v		
Manual/packaging					✓	v				

After going through various calculation and optimisation steps, we have successfully assigned appropriate workers to corresponding operations based on their skills and abilities. This careful selection process ensures that the right worker is assigned to the right operation, maximising efficiency and productivity in our workshop. The final result is presented in the balancing table below (Table 9).

Table 9: Balancing table

N°	Operation	Machine	Worker	W3	W7	W10	W5	W2	W9	W4	W1	W8	W6
			Pace	**100**	**100**	**90**	**110**	**100**	**100**	**90**	**95**	**100**	**110**
			Time										
1	Stitch the lace at the front	3-thread overlock	120	60	60								
2	Stitch the lace at the front neckline	3-thread overlock	60			60							
3	Stitch the lace at the back neckline	3-thread overlock	60				60						
4	Stitch the lace at the sleeves	3-thread overlock	45					45					
5	Close side	4-thread overlock	50						50				
6	Roll up the sleeves	4-thread overlock	40							40			
7	Topstitch armholes	Lockstitch machine	45								45		
8	Low hem	3-thread overlock	40					20		20			
9	Peeling	Manual	18								18		
10	Control	Manual	33									33	
11	Ironing	Manual	30										30
12	Super control	Manual	23									23	
13	Packaging	Manual	33										33
			Workload	60	60	60	60	65	50	60	63	56	63
			Potential	59.7	59.7	53.73	65.67	59.7	59.7	53.73	56.72	59.7	65.67
			Saturation	1.01	1.01	1.12	0.91	1.09	0.84	1.12	1.11	0.94	0.96

The balancing value, which was calculated by taking the average of all the saturation values, resulted in a value of 1.01. This value is considered excellent, indicating a high level of balance and efficiency in the distribution of tasks among the workers.

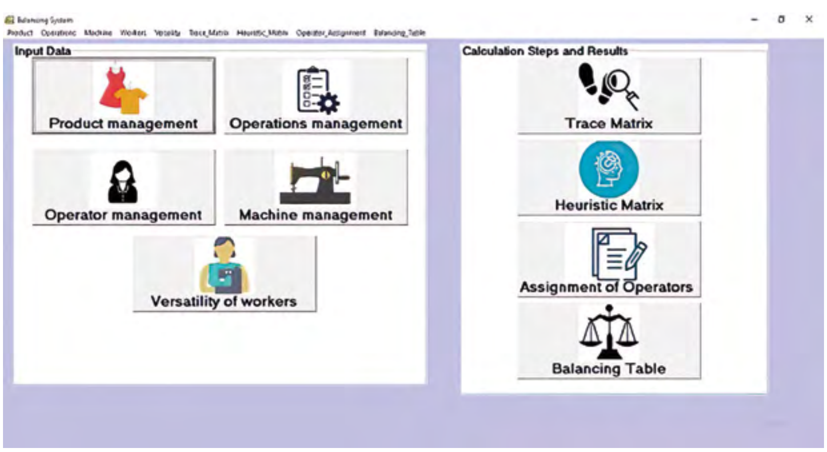

Figure 6: Main window of program developed

4.4 Presentation of developed program

Our designed program consists of two main components, i.e. the input data, which includes essential information such as the product, operations, machines and worker versatility, and the calculation steps and resulting output.

The calculation program follows a series of steps before obtaining the final result displayed in the balancing table. These steps include the trace matrix, heuristics matrix and operations assigning. Each step is crucial in the calculation process and contributes to the generation of the balancing table.

5 Conclusion

The balancing values obtained from the program's execution indicate a successful optimisation of workload distribution among operators. Using the ant colony balancing technique with the enhancement method gave acceptable and more optimised results. Indeed, the improvement procedures pushed the solution's quality to improve.

In conclusion, developing an automatic balancing application for a fashion company using artificial intelligence represents a transformative leap ahead in fashion and manufacturing. This innovative solution harnesses the power of Al to optimise inventory management, reduce costs and enhance customer satisfaction. Similarly, the automatic balancing application promises to improve the customer experience by ensuring that products are consistently available, meeting demand and maintaining competitive pricing.

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Artificial Intelligence in the Fashion and Apparel Industry
Umetna inteligenca v modni in oblačilni industriji

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Abstract
In recent times, there has been significant interest in incorporating artificial intelligence (AI) in the fashion and apparel industry, as it has the ability to bring about significant transformations across different aspects of the sector. This comprehensive review offers a systematic examination of current AI applications in fashion, and discusses implications and future opportunities. The study investigates AI uses in the sector, with a focus on virtual try-on technology, personalized recommendations, AI-driven design and supply chain optimization. This analysis explores the benefits and constraints of these applications, and is supported by real-world case studies showcasing successful deployments. The review examines how AI influences consumer insights and market trends, and highlights the effectiveness of sentiment analysis and social media monitoring as tools for understanding consumer preferences and the shaping of brand perception. It also emphasizes AI's role in analysing market trends, enabling the identification of emerging fashion trends through AI-driven market research tools. This study provides a glimpse into future possibilities and advancements AI can introduce to fashion, including potential integration with augmented reality (AR), innovative applications in fashion shows and events, and the potential to revolutionize traditional business models. This review consolidates primary findings on the introduction of AI in the fashion and apparel sector, and emphasizes AI's potential to enhance consumer experiences, sustainability practices and market efficiency.
Keywords: AI-driven design, artificial intelligence, fashion industry, virtual try-on, sustainability

Izvleček
V zadnjem času je veliko zanimanja za vključevanje umetne inteligence (UI) v modno in oblačilno industrijo, saj omogoča pomembne preobrazbe v različnih vidikih teh sektorjev. Članek podaja sistematičen pregled trenutnih aplikacij UI v modi in razpravo o posledicah in priložnostih. Predstavljena uporaba UI se osredinja na tehnologijo virtualnega preizkušanja, personaliziranje priporočil, oblikovanje, ki ga vodi UI, in optimizacijo dobavne verige. Podane so prednosti in omejitve teh aplikacij, podprte s študijami uspešno izvedenih primerov iz resničnega sveta. Predstavljen je vpliv UI na poglede potrošnikov in tržne trende, pri čemer je izpostavljena učinkovitost analize razpoloženja potrošnikov in spremljanja družbenih medijev kot orodij za razumevanje preferenc potrošnikov in oblikovanje dojemanja blagovne znamke. Prav tako poudarja vlogo UI pri analizi tržnih trendov, ki omogoča

prepoznavanje nastajajočih modnih trendov s pomočjo orodij za tržne raziskave, ki jih poganja UI. Raziskava podaja vpogled v možnosti in napredek, ki jih UI lahko v prihodnosti uvede v modo, vključno z možnostjo integracije z obogateno resničnostjo, inovativnimi aplikacijami na modnih revijah in dogodkih ter potencialom za revolucionarne spremembe na področju tradicionalnih poslovnih modelov. V tem preglednem članku so združene glavne ugotovitve o uporabi umetne inteligence v modni in oblačilni industriji, poudarjen je potencial umetne inteligence za izboljšanje izkušenj potrošnikov, trajnostnih praks in tržne učinkovitosti.
Ključne besede: oblikovanje s pomočjo UI, umetna inteligenca, modna industrija, virtualno preizkušanje, trajnost

1 Introduction

The dynamic fashion and apparel industry continuously seeks innovative strategies to meet consumer demands and maintain competitiveness, with artificial intelligence (AI) emerging as a transformative force. This study provides a comprehensive analysis of AI's diverse applications in revolutionizing customer experiences and business models. By leveraging AI, fashion companies can make data-driven decisions, innovate offerings, and adopt sustainable, customer-centric practices.

AI is a branch of computer science that enables machines to execute tasks that typically require human intelligence. AI systems analyse extensive datasets, identify patterns, and make predictions or decisions based on the acquired knowledge. Techniques such as machine learning, deep learning, natural language processing and computer vision have revolutionized industries like healthcare, finance, transportation and entertainment. In the fashion and apparel industry, AI has become a transformative force, providing innovative solutions to streamline operations, enhance customer experiences, and support sustainable practices. Leveraging AI technologies, fashion businesses can gain valuable insights, optimize supply chains, improve product design, and foster personalized connections with customers [1].

The significance of AI in the fashion industry lies in its ability to address crucial challenges and seize emerging opportunities. Primarily, AI-driven technologies empower fashion companies to leverage the wealth of available data. With the proliferation of social media, e-commerce platforms and connected devices, an abundance of consumer and market data is accessible. Through AI-driven analytics and algorithms, this data can be processed to uncover hidden patterns and generate actionable insights, thus facilitating design, marketing and sales strategies [2]. The use of AI not only reduces a company's expenses and delivers personalized communication services, but it also tracks social media and various data sources, analysing past behaviours to predict upcoming fashion trends [3].

Furthermore, AI allows fashion brands to provide personalized recommendations to consumers. By analysing individual preferences, purchase history and browsing behaviour, AI algorithms can suggest products that align with each customer's unique style, size and preferences. This level of personalization enhances the overall shopping experience, elevates customer satisfaction and drives higher conversion rates.

Moreover, AI has the potential to revolutionize the design process. Generative models, powered by deep learning, allow designers to explore countless creative possibilities, resulting in novel and innovative designs. It has been studied by many fashion and apparel researchers in different aspects [4]. AI can also assist in trend forecasting by analysing fashion-related content on social media and other online platforms to identify emerging trends, and thus enable brands to stay ahead of the curve and respond quickly to shifting consumer preferences. It has been observed that AI, together with its application in metaverse fashion, has played a significant role in reshaping digital fashion technology [5].

2 AI applications in fashion and apparel

AI has emerged as a revolutionary force in the fashion and apparel industry, fundamentally transforming the way businesses operate and engage with consumers. With its capacity to analyse extensive datasets, recognize patterns and make data-driven decisions, AI is reshaping various facets of the fashion ecosystem, from design and manufacturing to marketing and customer interactions. In this era of digitalization and rapidly evolving consumer preferences, fashion brands are increasingly turning to AI-driven solutions to remain competitive and cater to their tech-savvy and discerning customers. AI applications in the fashion realm encompass a wide array of technologies and techniques, including virtual try-on, personalized recommendations, AI-driven design, apparel supply chain optimization, trend forecasting and sustainability initiatives. This exploration of AI applications in the fashion and apparel industry will delve deeply into the benefits, limitations and successful case studies of various AI-driven solutions. From enriching customer experiences through virtual try-on technology to optimizing production processes with AI-driven design tools, this review aims to provide a comprehensive understanding of how AI is revolutionizing the fashion landscape. It has been observed that AI powered fashion brands are exploiting technology to improve fashion consumers' online shopping behaviour by incorporating predictive models for recommendation purposes [6–7]. Similarly, the user experience of a virtual reality fashion store can also be improved by incorporating AI-based solutions such as generative clothing development and AI-aided digital fashion drawing [8–9].

By harnessing the potential of AI, fashion businesses can acquire valuable insights, create personalized shopping experiences, improve operational efficiency and align their offerings with emerging trends and consumer preferences.

2.1 Virtual try-on technology

The application of artificial intelligence in the fashion and apparel industry has witnessed a groundbreaking innovation known as virtual try-on technology. This revolutionary technology enables customers to virtually try on clothing and accessories in a digital setting, and offers a realistic and interactive shopping experience without the necessity of physical fitting rooms [10]. By utilizing augmented reality (AR) and virtual reality (VR) technologies, virtual try-on has garnered substantial acclaim, completely transforming the online fashion shopping process [11].

2.2 Advantages of virtual try-on technology

Virtual try-on tech improves the shopping experience, enabling the real-time visualization of clothing on customers. This reduces uncertainty, lowers return rates and boosts conversion rates for online retailers. Integration with AI-driven recommendations adds personalization based on style and body type, enhancing satisfaction and loyalty through tailored suggestions derived from customer data [12].

Virtual try-on also brings cost and time savings to fashion brands. Because it reduces the need for physical inventory and costly sample production, brands can showcase a broader range of products virtually, thus cutting down on manufacturing and logistics costs. Moreover, virtual try-on experiences can be shared on social media platforms, generating user-generated content and increasing brand visibility through organic marketing. Customers sharing their positive experiences with the technology can create a ripple effect, leading to increased engagement and exposure for a brand [13].

Hence, virtual try-on technology revolutionizes the way customers shop for fashion items online, providing a more personalized, cost-effective and engaging experience. Its ability to increase conversion rates and reduce return rates makes it a powerful tool for fashion retailers seeking to stay competitive in the digital age. Additionally, the integration of AI-driven recommendations further enhances the personalization aspect, making virtual try-on a game-changer in the fashion industry.

2.3 Limitations of virtual try-on technology

Virtual try-on technology has become a game-changing AI application in the fashion and apparel industry, providing customers with the ability to virtually try on clothing and accessories. However, despite the progress made, there are still challenges in achieving complete accuracy and realism, especially when it comes to complex materials and fabric patterns. Additionally, virtual try-on applications require devices with AR or VR capabilities, potentially limiting accessibility for some users. Moreover, these systems may not cater to all body types and diverse shapes, leading to the potential exclusion of certain customer segments. Nevertheless, various fashion brands have successfully implemented virtual try-on technology, leading to enhanced shopping experiences for their customers. For example, ASOS introduced the Virtual Catwalk feature, which allows users to virtually try on clothing items using AR technology on their mobile app [14]. Gucci incorporated virtual try-on on their website for sunglasses, offering customers a fun and interactive experience while boosting their confidence in purchase decisions. Similarly, Warby Parker's virtual try-on tool, powered by AR technology, enables customers to see how different eyewear frames look on their faces in real-time, streamlining the selection process and reducing returns [15].

Overall, virtual try-on technology offers compelling advantages in improving the customer experience, increasing conversion rates and enabling personalization, as seen in successful implementations by various fashion brands. Although certain limitations persist, continuous advancements in AI and AR technologies are expected to address these challenges, positioning virtual try-on as an indispensable tool for fashion retailers in the future [16].

3 Personalized recommendations

Personalized recommendations have become a crucial element in the digital transformation of the fashion and apparel industry, fuelled by advancements in AI and data analysis. With an overwhelming array of options available in a crowded market, providing individualized product suggestions has proven highly effective in boosting customer engagement and driving sales.

AI-driven recommendation systems in the fashion industry analyse extensive data, such as historical purchase behaviour, browsing patterns and demographic information to understand the unique preferences of each customer. Through machine learning algorithms, these systems accurately predict and propose products that align with individual styles, sizes and tastes.

The advantages of personalized recommendations are significant. Firstly, customers are more likely to discover products that resonate with their personal preferences, leading to increased satisfaction and brand loyalty. Secondly, tailored recommendations create a more personalized and engaging shopping experience, akin to the attentive service provided by an in-store stylist. For fashion businesses, personalized recommendations also yield higher conversion rates and increased average order values. By strategically presenting complementary products and relevant accessories, retailers can effectively upsell and cross-sell, and thus maximize revenue opportunities. Leading fashion e-commerce platforms showcase successful examples of personalized recommendation systems. These AI-driven engines continuously learn and adapt to individual customer behaviours, curating product suggestions based on browsing and purchase history to create seamless and personalized shopping journeys. Despite the numerous benefits, personalized recommendations also come with challenges that demand attention. Data privacy and protection are paramount, as customers entrust their data to these recommendation systems. Fashion brands must prioritize data security and transparently communicate their data practices to establish trust with their customers [17].

3.1 Collaborative filtering algorithms

Collaborative filtering is a potent technique used in the fashion industry for personalized product recommendations. These algorithms analyse user interactions and preferences, suggesting items similar to those liked or purchased by other users. By leveraging collective behaviour, collaborative filtering enhances user engagement, product discovery and customer retention. However, challenges such as the cold start problem and data sparsity require attention.

To tackle the cold start problem for new users, fashion brands can employ hybrid recommendation systems that combine collaborative filtering with other techniques such as content-based filtering or demographic information. In this way, relevant recommendations can be provided even with limited historical data. Addressing data sparsity involves techniques such as matrix factorization or using advanced machine learning models that handle sparse data more effectively. Encouraging users to provide feedback and ratings can also enrich the data and improve recommendation accuracy. Collaborative filtering algorithms are pivotal in creating personalized shopping experiences, and drive customer satisfaction and boost sales for fashion retailers. As AI technology advances, collaborative filtering is likely to become more sophisticated, enabling fashion brands to deliver even more accurate and meaningful recommendations to customers. By refining these algorithms and addressing their limitations, fashion companies can stay at the forefront of customer-centric retail and foster long-lasting relationships with their audience [18].

3.2 Deep learning approaches

Deep learning, a subset of artificial intelligence, has become a driving force in the fashion industry, leveraging its ability to process vast amounts of data and extract intricate patterns. This technology has transformed various aspects of the fashion ecosystem, from design and manufacturing to marketing and customer experience. One of the primary applications of deep learning in fashion is image recognition and product classification. Convolutional neural networks (CNNs) are instrumental in accurately classifying clothing items, accessories, and patterns, streamlining product categorization and inventory management in e-commerce platforms [19].

In the realm of fashion design, deep learning approaches. such as generative adversarial networks (GANs consisting of generator and discriminator neural networks), have proved invaluable. GANs can generate novel and visually appealing designs by learning from existing fashion datasets, inspiring designers' creativity and leading to the development of entirely new collections. Moreover, deep learning models, such as recurrent neural networks (RNNs) and transformers have been employed for textile pattern generation. These models can efficiently create diverse and intricate designs that align with current trends or specific brand aesthetics, offering a time-saving alternative to manual pattern creation [20]. Deep learning algorithms have significantly enhanced personalized fashion recommendations by analysing customer data, including browsing history and purchase behaviour, to suggest clothing items tailored to individual preferences, body shape and style, thus boosting customer satisfaction. Moreover, deep learning has revolutionized trend forecasting in the fashion industry by analysing real-time social media posts, fashion blogs and runway images to identify emerging trends, enabling brands to stay ahead of evolving consumer preferences. Another exciting application is the development of realistic virtual try-on technology, which combines deep learning, computer vision and augmented reality (AR) to offer customers an immersive shopping experience. However, implementing deep learning in fashion faces challenges, including the need for substantial computational resources and large datasets for effective training, which can be costly for some companies. Additionally, ensuring ethical use and addressing biases in training data are crucial for responsible and equitable AI application in the industry.

3.3 User experience and customer satisfaction

In today's competitive fashion market, a brand's success relies heavily on user experience (UX) and customer satisfaction. Within the fast-paced fashion industry, delivering a seamless and enjoyable user experience is vital for fostering customer loyalty and driving repeat business. Fashion e-commerce platforms and mobile apps must prioritize intuitive interfaces for effortless navigation and efficient product searches. AI-driven personalized recommendations enhance the user experience by tailoring product suggestions based on past behaviour, thus fostering individuality and engagement. Integrating virtual try-on technology and AR applications allows customers to visualize items before purchase, boosting confidence and reducing returns [21]. A streamlined checkout process with multiple payment options ensures a positive experience. With the growing prevalence of mobile shopping, optimizing websites and apps for mobile devices is essential. Responsive customer service that addresses inquiries promptly builds trust, while post-purchase engagement through updates and personalized recommendations maintains a connection and encourages repeat business. Addressing sustainability and ethical practices is increasingly important, with brands prioritizing ethical sourcing and transparent manufacturing to improve customer satisfaction and attract socially conscious consumers [22].

Providing a platform for customer reviews and feedback benefits both shoppers and brands. It helps customers make informed decisions while providing valuable insights for brands to refine their offerings. By focusing on user experience and customer satisfaction, and leveraging technologies such as AI, AR and personalized recommendations, fashion brands can foster brand loyalty and achieve sustainable growth in the competitive industry.

4 AI-driven design and creativity

AI-driven design and creativity have become transformative forces in the fashion and apparel industry, reshaping how products are conceived, developed and brought to market. With artificial intelligence at their disposal, fashion brands can optimize design processes, stimulate creativity and meet the ever-changing demands of consumers.

Adobe has just revealed its innovative and fully interactive garment called "Project Primrose," a revolutionary digital dress. The dress incorporates sequins that serve as "reflective light-diffuser modules", utilizing liquid crystals similar to those found in smart lighting technology.

Through generative design using AI algorithms such as generative adversarial networks (GANs consisting of generator and discriminator neural networks), designers can access a wealth of novel design ideas from existing datasets, which serve as inspiration or starting points for their creative exploration. This expedites the design ideation phase and opens up possibilities for innovative and distinctive styles. AI also enables style transfer, allowing fashion designers to experiment with diverse aesthetics, patterns and artistic influences, leading to the creation of unique and eclectic designs that resonate with specific target audiences, as shown in Figure 1. Moreover, AI-driven design facilitates customization and personalization by modifying designs based on individual preferences, body measurements and style choices, producing exclusive and tailored fashion items for each customer [23].

AI's ability to analyse vast fashion-related data in real time, including social media trends and historical sales data, allows brands to forecast emerging fashion trends promptly and design products that cater to current market demands. Furthermore, AI-based tools automate pattern and textile design, generating intricate and original patterns that align with brand identity while allowing designers to focus on higher-level creative tasks.

Figure 1: AI-generated innovative silhouetted high fashion garment

In terms of sustainability, AI optimizes material usage, reduces waste and suggests eco-friendly alternatives in design, thereby promoting responsible practices. AI-driven design tools facilitate rapid prototyping and iteration, fostering innovation and refinement. Collaborative platforms enable seamless teamwork and knowledge sharing, and thus transcend geographical barriers for diverse and innovative designs. While AI enhances creativity, human ingenuity remains essential. Integrating AI allows designers to push boundaries, respond efficiently to industry demands and balance innovation with customer-centricity.

4.1 Generative models and design tools

Generative adversarial networks (GANs), consisting of generator and discriminator neural networks, iteratively produce novel fashion concepts, and thus inspire designers. Deep learning-driven style transfer tools allow designers to apply artistic styles to images, leading to diverse design possibilities. The fashion and apparel industry has been revolutionized by generative models and AI-driven design tools that offer innovative methods to create, customize and visualize designs. These technologies transform sketches into intricate designs, inspire creativity and personalize products for customers. They optimize supply chains with real-time analytics and enhance marketing through trend identification and personalized content creation [24]. In-store, AI improves layouts, labour allocation and real-time workforce support, while also aiding organizational functions such as employee training and client relationship management. These tools incorporate customer preferences to offer personalized clothing and accelerate the design process with rapid prototyping and iteration. Additionally, AI automates pattern and textile design, thereby saving time and aligning patterns with brand aesthetics [25].

Moreover, generative models excel in trend analysis and forecasting by analysing extensive fashion data, enabling brands to design products that resonate with consumers and stay competitive. AI-driven collaborative platforms facilitate seamless teamwork among designers globally, and thus foster knowledge sharing and innovation. By adopting these tools, fashion brands can enhance creativity, optimize design processes and create products aligned with market trends and individual preferences, thereby engaging customers and maintaining a leading position in the evolving fashion industry.

4.2 AI as a co-creative partner

The fashion and apparel industry is increasingly recognizing the value of AI as a collaborative partner in the creative process. Rather than replacing human designers, AI complements their skills by providing data-driven insights, accelerating design processes and broadening design possibilities. AI's data-driven capabilities offer designers valuable inspiration by analysing vast amounts of fashion-related data, identifying emerging trends and understanding consumer preferences. During the ideation phase, AI-driven generative models generate diverse design concepts, sparking creativity and providing fresh ideas for designers to explore further.

Additionally, AI enables rapid design iteration, thereby allowing designers to quickly prototype and refine multiple variations of their creations. It also facilitates personalization and customization, and thus the tailoring of designs to meet individual customer preferences and measurements. AI's impact extends to sustainable design practices by suggesting eco-friendly materials and optimizing patterns to reduce waste, thereby contributing to more environmentally conscious fashion. Moreover, AI-driven design tools streamline workflows, thereby automating repetitive tasks and offering intelligent design recommendations, allowing designers to focus on more creative aspects. Through augmented reality (AR) applications, AI helps designers visualize and interact with their creations in a virtual environment, thereby enhancing creativity and understanding [26]. Consumers should be aware of how their data will be used and have the option to opt-out of data collection or AI-driven customization [27, 28].

AI fosters designer collaboration, enabling co-creation and knowledge sharing, irrespective of location. However, it is crucial to maintain a balance between human creativity and AI-driven insights. Designers should retain their artistic vision, and utilize AI as an enhancer rather than a replacement. This synergy of AI's potential and human creativity fuels innovation in the fashion industry, thereby ensuring its evolution in a competitive landscape.

5 Supply chain optimization

The fashion industry has significantly transformed with the integration of artificial intelligence (AI) in supply chain operations, which has enhanced efficiency and cost-effectiveness. AI-driven technologies provide valuable insights and analytics, enabling data-driven decision-making and swift adaptation to market dynamics. A key application is demand forecasting, where historical data and market trends are analysed to accurately predict product demand, optimize inventory levels, reduce costs and improve overall management. AI also aids in inventory optimization by considering factors such as product popularity and seasonality [29]. Supplier management benefits from AI's ability to evaluate supplier performance and reliability, thereby minimizing supply chain disruptions. In logistics and transportation, AI identifies optimal routes and provides real-time tracking, and thus increases efficiency. Warehousing is enhanced with AI-driven robotics, which reduce errors and expedite order fulfilment. Additionally, AI streamlines production planning and scheduling, thus cutting lead times, and supports risk management by identifying potential disruptions and facilitating contingency planning [30].

AI-driven supply chain optimization allows fashion brands to make informed decisions, enhance customer satisfaction and maintain competitiveness. By leveraging AI's capabilities in supply chain management, the fashion and apparel industry achieves greater efficiency, sustainability and profitability.

5.1 Predictive analytics in inventory management

Predictive analytics, a potent AI-driven tool, is revolutionizing inventory management in the fashion industry. By analysing historical data, market trends and other relevant factors, predictive analytics allows fashion brands to accurately forecast future demand and optimize inventory levels. This data-driven approach brings several advantages, including efficient inventory planning, the anticipation of trends, and the minimization of overstock and out-of-stock situations. It also streamlines replenishment processes, enables data-driven purchasing decisions, and assists in seasonal and promotional planning. By leveraging predictive analytics, fashion companies can improve profitability, reduce costs and enhance customer satisfaction, allowing them to stay competitive and agile in a rapidly changing market.

5.2 AI for demand forecasting

AI-driven demand forecasting is revolutionizing inventory management in the fashion industry by analysing extensive historical sales, customer and market data to identify intricate patterns, and thus surpass human forecasting capabilities. Machine learning models, such as time series analysis and neural networks, continuously refine predictions with new data. AI adeptly detects seasonality and fashion trends, enabling brands to anticipate demand fluctuations and adjust inventory accordingly [31]. By incorporating external factors such weather and economic indicators, AI generates comprehensive forecasts. It segments customers based on preferences, thereby facilitating personalized forecasts and tailored strategies. Real-time forecasting enables rapid market response, while AI optimization minimizes holding costs and excess stock, and thus enhances cash flow. Collaborative forecasting aligns the entire supply chain, thereby reducing stockouts. Ultimately, AI facilitates data-driven decisions, boosts supply chain efficiency, enhances customer satisfaction and maintains competitiveness in the fashion industry [32].

5.3 Supply chain efficiency and sustainability

Supply chain efficiency and sustainability are of utmost importance for the fashion and apparel industry, and AI-driven technologies are becoming instrumental in achieving these goals. With growing consumer awareness about environmental and ethical concerns, fashion brands are turning to AI to revolutionize their supply chain practices. AI's impact is far-reaching, and enhances efficiency and sustainability through various means. Firstly, AI-driven demand forecasting and inventory management enable brands to maintain optimal inventory levels, thereby reducing waste and overproduction. This leads to more efficient resource utilization. Secondly, AI optimizes logistics and transportation, enabling faster and eco-friendly product deliveries by identifying efficient routes and modes of transportation. Thirdly, AI helps identify sustainable materials for fashion products, and thus reduces the industry's environmental footprint. Furthermore, AI facilitates circular fashion practices such as recycling and upcycling, thereby extending garment lifespan and reducing waste. Ethical supply chain management is also enhanced by AI, and ensures fair labour standards are upheld. Waste reduction is achieved by AI-driven process optimization, and thus streamlines production processes and minimizes waste [33]. AI optimizes energy use, thereby cutting emissions. It enhances transparency through blockchain and aids in ethical consumer choices. The introduction of AI benefits fashion financially and ethically, thereby aligning with sustainable preferences.

6 AI in consumer insights and market trends

AI-driven technologies have completely revolutionized the methods by which fashion brands collect consumer insights and identify market trends. These innovations have empowered fashion companies to gain a deeper understanding of their target audience, accurately predict market shifts and outperform their competitors. AI's impact on consumer insights and market trend analysis is evident in several key areas. Firstly, using AI-driven sentiment analysis tools, fashion companies can analyse vast amounts of data from various sources, such as social media, product reviews and customer feedback, to gauge consumer sentiment towards their brands and products. This valuable information enables brands to comprehend customer preferences, identify pain points and proactively address any issues that arise. Secondly, AI enables personalized recommendations for individual customers based on their preferences and behaviour. By analysing past purchases and browsing history, AI tailors product recommendations to each customer's specific tastes, leading to increased customer satisfaction and higher conversion rates. Thirdly, AI plays a significant role in market trend analysis by analysing data from diverse sources such as fashion shows, influencers and online fashion platforms, to identify emerging trends. By identifying patterns and correlations, AI helps fashion brands stay ahead of the latest fashion movements and adapt their collections accordingly. Additionally, AI-driven demand forecasting models leverage historical data and market trends to accurately predict future demand for fashion products. This proactive approach enables fashion companies to optimize their inventory levels and reduce the risk of out-of-stock or overstocking situations. AI also aids in customer segmentation, where it can categorize customers based on various attributes such as demographics, purchasing behaviour and preferences [34]. This segmentation allows fashion brands to target specific customer groups with tailored marketing campaigns and product offerings. Furthermore, AI-driven pricing models can analyse market dynamics and competitor pricing to determine the optimal price for fashion products, thereby maximizing revenue while remaining competitive in the market. The real-time data analysis capabilities of AI allow fashion brands to monitor customer behaviour and market trends in real-time, enabling quick adjustments to marketing strategies and product offerings to meet changing consumer demands. Lastly, AI's image and visual analysis capabilities allow fashion brands to understand style trends, colour preferences and design elements that resonate with consumers, and thus aid in the creation of products that align with current fashion aesthetics [35]. By leveraging AI for consumer insights and market trend analysis, the fashion and apparel industry can devise data-driven strategies that result in improved customer engagement, increased sales and a competitive edge in a rapidly evolving market. AI's ability to process and analyse vast amounts of data in real-time allows fashion brands to make informed decisions and deliver personalized experiences that deeply resonate with their target audience.

6.1 Sentiment analysis and social media monitoring

Sentiment analysis and social media monitoring are crucial AI-driven tools that are transforming how fashion brands understand consumer sentiment, evaluate brand perception and make data-driven decisions. These technologies enable fashion companies to stay connected to their audience, manage their online reputation effectively and respond promptly to customer feedback. Sentiment analysis, which uses natural language processing and machine learning, assesses and categorizes opinions expressed in text data, such as social media posts, product reviews and customer feedback, giving fashion brands valuable insights into customer feelings about specific products, brand campaigns and overall shopping experiences. By tracking sentiment on social media platforms and review sites, brands can maintain a positive brand image, foster customer loyalty and identify areas for product improvement. AI-driven social media tools analyse competitor activity, gauge influencer campaign impact and assess consumer perceptions. They offer real-time feedback, and thus aid issue resolution and relationship building. Through sentiment analysis, fashion brands gain insights for smart marketing, improved customer experiences and a competitive edge in the industry [36].

6.2 Understanding consumer preferences

AI-driven technologies have transformed how the fashion industry understands consumer preferences, thereby leveraging algorithms to collect and analyse data effectively. By harnessing AI, fashion brands offer personalized product recommendations based on individual purchase histories and browsing behaviours, enhancing customer satisfaction and fostering loyalty [37]. AI's customer segmentation capabilities enable targeted marketing efforts, and thus maximize impacts across demographics and shopping behaviours. Social media analysis driven by AI provides insights into consumer conversations and emerging trends, while sentiment analysis evaluates feedback for improved understanding of customer satisfaction levels [38]. Additionally, AI's image analysis identifies popular fashion trends, and thus guides product development and marketing strategies. Real-time feedback analysis enables brands to be responsive to customer needs, thereby enhancing relationships and gaining a competitive edge in the market.

6.3 AI in market trend analysis

AI has revolutionized market trend analysis in the fashion industry by swiftly processing extensive data in real-time. It gathers insights from diverse sources, including social media, online shopping behaviour and fashion blogs, using sophisticated natural language processing (NLP) and image recognition algorithms. This allows AI systems to grasp consumer sentiments, preferences and reactions to various fashion trends. By embracing AI for market trend analysis, fashion brands can swiftly identify emerging trends, cater to individual preferences, optimize inventory management, and enhance design and product development choices. AI also aids in monitoring competitor strategies, improving marketing campaigns and predicting future market trends. Ultimately, AI allows fashion brands to make data-driven choices, maintain a competitive edge and offer personalized experiences that deeply resonate with their customers.

6.4 Identifying emerging fashion trends

AI-driven market research tools have fundamentally transformed the fashion industry's approach to consumer data analysis, thereby delivering crucial insights for strategic decision-making. These cutting-edge tools utilize artificial intelligence and machine learning algorithms to process vast and diverse data from social media, online forums, customer reviews and e-commerce platforms. With the aid of natural language processing (NLP) and image recognition technology, they understand consumer sentiments and preferences expressed in unstructured text and visual content related to fashion trends. The key advantage of these AI-driven tools lies in their ability to uncover hidden patterns and emerging trends that traditional research methods might miss. They provide real-time insights into consumer behaviour shifts, popular styles and emerging fashion trends, enabling brands to be proactive in adapting their product offerings and marketing strategies [39]. By monitoring consumer sentiment, brands can assess campaign success and address potential issues promptly. AI-driven market research tools are highly effective in customer segmentation, and categorizing audiences based on demographics, shopping behaviour and lifestyle preferences. This segmentation allows fashion companies to personalize marketing messages and product recommendations, thereby enhancing customer satisfaction and conversion rates. Additionally, these tools facilitate comprehensive competitor analysis, and help brands identify opportunities and refine their own strategies to gain a competitive edge. The integration of AI streamlines the market research process, and thus significantly reduces manual effort and accelerates data analysis. Brands can process vast amounts of data efficiently, thus facilitating rapid and precise data-driven decisions [40].

Hence, AI-driven market research tools have revolutionized the fashion industry's understanding of consumer preferences and market trends. By harnessing the power of artificial intelligence, fashion brands gain valuable insights into consumer behaviour, emerging trends and the competitive landscape. These tools enable personalized experiences, optimized marketing efforts and informed decision-making, and ultimately drive growth and success in the dynamic and ever-evolving fashion market.

7 AI and sustainability in fashion

AI has emerged as a transformative force in the fashion industry, and allowed brands to tackle environmental and ethical challenges and promote sustainability. By harnessing AI-driven technologies, fashion companies can drive positive change across various areas, such as material sourcing, manufacturing processes, waste reduction and supply chain management. A significant contribution of AI lies in sustainable material sourcing. By analysing extensive databases, AI algorithms can identify eco-friendly materials, thereby reducing reliance on traditional materials with a greater environmental impact [41]. This allows brands to make responsible choices when selecting fabrics and materials for their products.

AI also plays a crucial role in waste reduction and manufacturing optimization. By analysing production data and consumer trends, AI helps fashion companies predict demand more accurately, leading to more efficient production and reduced overproduction. Additionally, AI supports circular fashion initiatives by identifying opportunities for recycling and upcycling, extending the lifespan of products and minimizing waste. Supply chain management is another area where AI contributes to sustainability. AI-driven optimization helps brands reduce energy consumption, transportation emissions and overall inefficiencies. This minimizes the environmental footprint and promotes sustainable practices throughout the production and distribution process. Furthermore, AI supports sustainability by enabling brands to track and trace their supply chains, thereby ensuring transparency and accountability. Consumers increasingly seek information about product origins, and AI-driven traceability solutions provide real-time data on the journey of garments from raw materials to the finished product [42].

Hence, AI has become a powerful catalyst for sustainability in the fashion industry, offering innovative solutions to reduce environmental impacts and promote ethical practices. By integrating AI technologies into their operations, fashion brands can make significant strides toward a more sustainable and responsible future. As consumer awareness and demand for sustainable fashion grow, AI will continue to play a vital role in transforming the industry and driving positive change for the planet and society.

8 Future trends and opportunities

The future of AI in the fashion and apparel industry holds immense promise. As technology advances, AI is poised to have an even more significant impact on shaping the industry's landscape. AI-driven personalized shopping experiences will become increasingly sophisticated, providing consumers with tailored recommendations based on their preferences and behaviour. Furthermore, the integration of AI with emerging technologies such as virtual reality (VR) and augmented reality (AR) will transform how consumers interact with fashion products, offering virtual try-ons and immersive shopping experiences. AI will also play a pivotal role in driving sustainability efforts, optimizing supply chains, promoting circular fashion and fostering eco-friendly practices. The future of AI in fashion opens up endless possibilities for brands to elevate customer experiences, streamline operations, and create a more sustainable and innovative industry.

8.1 AI and augmented reality (AR) integration

The convergence of AI and augmented reality (AR) is a transformative trend in the fashion industry. By combining AI-driven personalization with AR's immersive capabilities, brands can provide customers with unparalleled virtual try-on experiences. AI-driven algorithms will enable virtual garments to adapt to individual body shapes, allowing consumers to visualize how the clothing will look and fit before making a purchase. This technology enhances customer engagement and reduces the need for physical try-ons, and thus promotes more efficient and sustainable shopping practices. The fusion of AI and AR opens up exciting opportunities for fashion brands to create innovative and interactive shopping experiences that bridge the gap between online and offline retail, and sets a new standard for personalized, convenient and engaging fashion retail [43].

8.2 AI in fashion shows and events

AI is poised to revolutionize the fashion show and event landscape, and will bring about significant changes in the way collections are presented and experienced. Fashion designers can now harness the power of AI-driven design tools to create innovative and boundary-pushing collections. Virtual fashion shows, incorporating AI-generated designs and digital models, provide a fresh platform for showcasing creativity and innovation on a global scale. Moreover, AI will optimize event planning and management, thereby streamlining logistics, predicting attendee preferences and tailoring experiences to individual tastes. Real-time audience sentiment analysis during events, powered by AI, will offer designers valuable feedback to refine their collections and understand consumer reactions. Through AI, fashion shows and events will evolve into immersive and data-driven experiences, and thus captivate audiences and propel the fashion industry to unprecedented levels of innovation.

9 Conclusion

The integration of artificial intelligence (AI) in the fashion industry is revolutionizing the sector. This review outlines AI's applications, challenges and future trends, and emphasizes its transformative potential. Key findings reveal that AI enhances customer experiences through virtual try-ons, personalized recommendations and co-creative designs. It optimizes supply chains, predicts demand and promotes sustainability by reducing environmental impacts. AI also helps brands understand consumer preferences and market trends, thereby enabling informed decision-making and strong brand perception. However, the adoption of AI comes with challenges, including data privacy, algorithmic bias and transparency. Addressing these issues is crucial for maintaining consumer trust and ensuring ethical AI use in fashion.

On the other hand, the implications of AI in the fashion and apparel sector are extensive. Brands that effectively harness AI technologies can gain a competitive edge by delivering personalized, sustainable and innovative fashion experiences to consumers. AI-driven design tools and virtual try-on technology have the potential to minimize material waste and inventory inefficiencies, thereby streamlining the entire fashion value chain. Furthermore, AI's capacity to identify emerging trends and consumer insights allows brands to remain relevant and agile in a rapidly evolving market.

The future of AI in the fashion industry is promising. Combining AI with augmented reality (AR) will create highly realistic virtual try-ons and immersive shopping experiences, and thus merge online and offline retail. AI-driven design will enhance creativity, and foster collaboration between AI systems and human designers. AI will also advance sustainability, and thus promote circular fashion and responsible supply chain management. Unlocking AI's full potential in fashion requires stakeholder collaboration, research and development investment, and the cultivation of AI expertise within fashion companies. AI is set to transform the industry by enhancing consumer experiences, driving sustainability and opening new creative avenues. With responsible implementation and ethical considerations, AI can make the fashion industry more dynamic, efficient and socially responsible. Embracing AI will foster a future where technology and creativity shape a more inclusive, sustainable and innovative fashion ecosystem.

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Willingness of Buyers to Buy Wearable Rejected Clothes from Clothing Manufacturers: Model for Fostering Sustainable Apparel Business

Pripravljenost kupcev za nakup zavrženih nosljivih oblačil: Model za spodbujanje trajnostnega poslovanja z oblačili

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Abstract

The apparel industry in Bangladesh produces rejected garments while manufacturing high-quality exportable garments. This industry faces challenges in managing rejected garments as they contribute to waste generation. The purpose of this study was to explore the current policy of managing rejected garments and look for a more sustainable business model or policy. This research collected opinions and information from 18 different garment manufacturing industries regarding rejected garments and buyers' and manufacturers' existing policies for managing the rejected garments. The results of the study show that there is no particular guideline from the buyers for managing rejected garments; consequently, the manufacturers handle these garments in their own way. A novel and more sustainable business model for the clothing business was proposed to align the business with the Sustainable Development Goal 12 (responsible consumption and production). This model urges collaborative efforts between buyers and manufacturers to capture more value from rejected garments and extend their lifecycle. The proposed framework will benefit relevant stakeholders, minimise waste generation and reduce the impact of fast fashion.
Keywords: rejected garments, sustainable business model, sustainable development goals, waste minimisation

Izvleček

Oblačilna industrija v Bangladešu proizvaja visokokakovostna oblačila za izvoz, sočasno pa tudi zavrže oblačila. Posledično se sooča z izzivi, kako ravnati z zavrženimi oblačili, ki prispevajo k nastajanju odpadkov. Namen raziskave je bil preučiti sedanjo politiko ravnanja z zavrženimi oblačili in poiskati bolj trajnostni poslovni model. V raziskavi so bila

zbrana mnenja in informacije 18 podjetij različnih panog proizvodnje oblačil glede završenih oblačil ter obstoječega odnosa kupcev in proizvajalcev do ravnanje z završenimi oblačili. Rezultati so pokazali, da kupci nimajo posebnih smernic za ravnanje z završenimi oblačili, zato proizvajalci z njimi ravnajo po lastni presoji. Na podlagi rezultatov je bil predlagan nov in bolj trajnosten poslovni model za ravnanje z oblačili, ki bi le-to uskladil z 12. ciljem trajnostnega razvoja (SDG 12; odgovorna potrošnja in proizvodnja). Model poziva k sodelovanju med kupci in proizvajalci, da bi bolje izkoristili završena oblačila in podaljšali njihov življenjski cikel. Predlagano bi koristilo vsem vpletenim deležnikom, zmanjšalo nastajanje odpadkov in zmanjšalo vpliv hitre mode.
Ključne besede: zavrnjena oblačila, trajnostni poslovni model, cilji trajnostnega razvoja, zmanjševanje količine odpadkov

1 Introduction

Textile waste can be categorised into three major categories, i.e. pre-consumer waste (e.g. left-over fabric due to excess booking or consumption saving, splicing loss in the cutting room, cutting waste etc.), post-industrial waste (excess manufacturing of garments, rejected garments etc.) and post-consumer waste. Post-consumer garments are those that are used and worn by consumers before reaching the end of their life cycle. By recycling, it is possible to make both conventional and technical textiles, while reusing the garments helps increase the life span of garments, reduces pressure on new cloth production and encourages a circular economy. Pre-consumer waste and post-consumer waste are generally managed by repurposing through recycling and sometimes by reusing [1, 2].

In the case of producing products at the mass level, it is almost impossible to run production activities with no faults or rejections. The rejected items that will not be able to serve the desired purpose are regarded as waste. In a sense, waste is unavoidable. In the apparel manufacturing industry, waste is in the form of rejected garments, trims, accessories or other materials [3]. In addition, the population is growing rapidly, and there has been a growing global economy and standard of living over the past few decades. Therefore, there has been a steady increase in both the manufacturing and consumption of apparel [4]. The production and design of garments prioritise rapid trend transitions, often resulting in the obsolescence and early disposal of these items, with the aim of generating quick profits. In contrast, sustainability and client preferences are not necessarily taken into consideration during this process [5]. The clothing, textile and fashion sectors are among the most contagious globally and generate a significant amount of clothing waste as a result of this business strategy [6].

The United Nations Member States endorsed the 2030 Agenda for Sustainable Development in 2015, which outlines 17 Sustainable Development Goals (SDGs). Given its global character and notable expansion in terms of consumption, the fashion industry stands out as one where the SDGs require the most commitment [7]. All the necessary resources are derived from nature, including raw materials, production facilities and local waste management. As a result, every corporate entity's main goal is to continue operating for a long time; hence, business executives must embrace sustainable development strategies, which motivate companies to put in place sensible safeguards to protect the environment from the negative effects of their operations [8]. A business model is a simple representation of the complexity of a value flow and the interaction between value elements. Although the incorporation of sustainability measures into the business model has been ignored, the business is now under pressure to adopt sustainability measures. However, incorporating sustainability into conventional business models is not appropriate for finding solutions. A sustainable business model minimises the harmful effects of business activities on the environment and society while simultaneously contributing to the economy and SDGs [9].

Materials used in the apparel industry constitute raw materials and energy, and the present "take-make-waste" system has increased the rate of depletion of our limited resources and is generating more waste. To close material cycles and move toward a circular economy, experts, manufacturers and professionals have become more interested in the efficiency and management of natural resources over the past few decades. A sustainable production model has emerged as a result of the pre-existing industrial paradigm. Additionally, apparel consumers are becoming more aware of the detrimental effects of the textile production and disposal on the environment and society [10]. The three main strategies and actions that propel the circular economy are reducing, reusing and recycling. These are the typical approaches to traditional waste management. Reduction refers to cutting waste at several stages of the product life cycle and throughout the production process (including low raw material usage). Using items for their intended use or other applications without significant alteration is known as the reuse technique. Recycling is the process of converting waste materials into raw materials or new products [11]. According to recent studies, approximately 75% of the materials used during and after clothing use are either incinerated or landfilled. Only 1% of the collected 23% of used garments undergo recycling into new textile fibres, while the rest undergo downcycling or sale in the second-hand market [12]. Moreover, the waste management technologies are under pressure due to the growing volume of waste. In that case, product destruction is not recommended as it opposes the philosophy of circular economy [13].

Several clothing retail businesses have implemented take-back programmes that give customers the possibility to return worn clothing to these establishments. Prominent fashion firms, e.g. Mark & Spencer, H&M and IKEA, exhibit a strong commitment to sustainable business practices through their recycling of textiles [14]. The textile and garment industry can become more sustainable by implementing a circular economy strategy, which reduces waste output, promotes product reuse and recycles rubbish into new items or raw materials. Since the circular economy reduces environmental effects while increasing revenue, it may also help businesses become more sustainable [15]. The reduce, reuse and recycle policy seems very promising for tackling the current linear economy problem. Nevertheless, the success of this policy will depend on the business model and how these strategies are used. The EU is exporting the used clothes to Asian and African countries to reuse them and extend their lifetime. In one sense, it seems very promising. However, a closer view of the data shows something interesting (Table 1). From Table 1, it is evident that the EU countries keep only small fractions of used garments for their own use and dump most of them to Africa and Asia, where there is less facility for recycling and ultimately aggregates as waste there.

Table 1: Resell percentage of used garments by EU [16]

Description	Percentage	Details of percentage
Resell used garments locally by EU country	10	
Resell used garment to any other EU countries	10	
Resell used garments to any other countries outside EU	20	Non-EU: 11% Africa: 46% (~40% is wasted) Asia: 41% Others: 2%

Businesses are under pressure to implement more environmentally friendly management practices owing to ecological principles and public expectations; however, some businesses are not driven to do so [17]. Recycling is an option for moving towards sustainability; however, the percentage is still low. Bangladesh is a hub for the clothing manufacturing industry. Bangladesh exported \$4.49 billion in

February 2024 from its RMG (readymade garment) sector [18], which also indicates the volume of exports by the country. To export such a large quantity, manufacturing must also be in huge amounts and there will be some rejections in manufacturing. Garments with some minor defects are sold locally in manufacturing countries; however, the authors have not found any proper guidelines or specific business models from buyers to do the business. This study has been conducted to find a solution regarding the management of rejected garments to do business in a more sustainable manner.

2 Methodology

2.1 Sampling

The following study was conducted using an online survey. A stratified sampling technique was adopted to select the participating companies and respective individuals who voluntarily answered the research questions. Sample individuals were selected based on the topic relevance, experience and sector. The companies were approached via face-to-face interviews, phones or email. Four selection criteria were chosen to carry out the survey, i.e. (i) the company has to be based in Bangladesh, (ii) the companies are conducive for promoting sustainability, (iii) the companies have to be export-oriented in the textile/apparel manufacturing industry, (iv) the companies have no problem disclosing or sharing information. We approached 25 companies with diverse textile industries, i.e. knitwear, dyeing/finishing, woven and denim industries. Most of the companies are located near or around Dhaka City.

2.2 Data collection and analysis

A set of questions was prepared in accordance with the research topic and to gain a deeper understanding of the perspectives of buyers towards sustainable practices by taking advice from academic and industrial experts. The questionnaire contained the following questions:

1. *Factory type:*
   - Knitwear
   - Denim/Jeans
   - Woven (other than denim/jeans)
   - Nonwoven
2. *Recommendation for sustainable strategy from buyer*:
   - Yes
   - No
   - No comment
3. *Major product of the factory:*
4. *Average cost of making of major product:*
5. *Annual average order quantity of major product:*
6. *Average rejection rate of the major product in final assembly process (sewing floor):*
7. *Buyer's comments about rejected garments for physical defects:*
   - Destroy the rejected garments
   - Keep it for a definite time period, after that sell them into local market
   - No specific instruction for the management of rejected garments
   - Manufacturers can sell them anywhere anytime
8. *Manufacturer's usual practice with rejected garments:*
   - Destroy the rejected garments
   - Sell them at lower price following buyer's instruction
   - Sell them at lower price without informing the buyers
   - Distribute them among the poor as per CSR activity
9. *The rejected garments are still wearable and functional enough to serve its purposes:*
   - Yes
   - No
10. *The manufacturers usually do some rework before selling them in local market:*
    - Always
    - Not necessary
    - Sometimes

11. *Buyers are willing to take the rejected garments after some rework:*
    - Yes
    - No
12. *The defects in the rejected garments are easily traceable by common people:*
    - Yes
    - No
    - Most of the defects are not traceable

Following the research design, the set of questions was sent to participants in different sections of the textile industry (knitting, weaving, dyeing and apparel manufacturing) holding senior positions (general manager, assistant general manager, executive director etc.). The set of questions was sent to the point of contact via email followed by oral confirmation via phone. The data obtained are presented in Tables 2 and 3. Factory data such as product category, annual order quantity, cost of manufacturing, and annual garment rejection rate was collected and set as benchmarks for comparison. To protect the interests of sample company interests, the name of each sample company remains confidential and a distinct code is assigned to recognise each company.

3 Results and discussion

The study was able to extract both quantitative and qualitative information from 18 interviews. The quantitative information represents the estimation of the order quantity of a major product category, cost of making (total material and manufacturing cost) and the annual garment rejection percentage after the final assembly of 18 different factories for six major product categories of that particular factory, as shown in Table 2. From the tabulated data (Table 2), it is visible that even a minor rejection percentage can incur a significant amount of loss annually. A real solution to minimise this loss is to sell the second category products in the local market at a reasonable price; the loss can thus be compensated or even a profit can be made.

Table 2: Factory-wise annual estimated order quantity, cost of manufacturing, rejection rate and cost incurred due to rejection of different product types

Factory code	Major product category	Estimated annual order quantity (EAOQ) (pcs)	Estimated cost of manufacturing (ECOM) (USD)	Estimated annual garment rejection after final assembly (EAR) (%)	Estimated cost of rejection (USD) = EAOQ × ECOM × EAR
F1	Babywear	500000	15	1.0	75000.00
F2	Babywear	6000000	3.5	5.0	1050000.00
F3	Denim pants	100000	6.5	3.0	19500.00
F4	Denim pants	1000000	24	2.0	480000.00
F5	Denim pants	1250000	5.45	2.5	170312.50
F6	Jacket	100000	9.8	1.5	14700.00
F7	Jacket	5000000	13	0.5	325000.00
F10	Polo shirt	1000000	10	3.0	300000.00
F8	Polo shirt	2000000	15.5	1.0	310000.00
F9	Polo shirt	2000000	16	5.0	1600000.00
F11	Sweat shirt	4000000	37	3.0	4440000.00
F12	Sweat shirt	20000000	14	1.0	2800000.00
F13	Sweat shirt	1200000	12	2.0	288000.00
F14	T-shirt	2000000	3	2.0	120000.00
F15	T-shirt	1800000	6.5	1.0	117000.00
F16	T-shirt	5000000	5	1.0	250000.00
F17	T-shirt	60000000	5	0.5	1500000.00
F18	T-shirt	2200000	4.5	1.0	75000.00

The qualitative information, as tabulated in Table 3, indicates that although most buyers want the manufacturers to be more sustainable, many of the buyers are willing neither to take back the rejected garments (considered wastage) nor to provide any specific guidelines to handle the garments in a sustainable way. Sometimes, the defects are so minor that they cannot be traced by common people. In the case of more severe defects, garments can still be made wearable after some rework. If buyers have any specific instructions, they are very likely to hold the garments for a specific time period, and sell them afterwards or destroy them. Storing the garments for some time is essential to buyers, as buyers have the right to bring their products to market before anyone copies them. Garments are usually destroyed for copyright purposes or if any harmful chemical substances are found in them. When there is no specific instruction for handling the rejected garment, manufacturers prefer selling it locally without informing the buyer to get some monetary benefit since the cost of manufacturing a garment is not very low. This overall current situation in the apparel business can be depicted through a model (Figure 1). Among the 18 factories surveyed, factories F5, F8 and F9 destroy the garments, while other factories attempt to minimise the loss by selling the garments at a cheaper price locally.

The major problem with the current rejected garment management policy is that there is no clear policy for second-quality garments. However, even a 1% rejection may incur a huge monetary loss for the manufacturers, which is evident from Table 2. Beyond the monetary value, each garment undergoes different manufacturing steps that require raw materials, water and energy [19]. Hence, it is better to keep them in the user cycle for as long as possible for the energy, water and carbon not to go into the vain.

Table 3: Summary of qualitative information of interview

Descriptor	Is the major buyer of the factory concerned about sustain-ability?	Is the buyer interested in taking rejected garments after some rework?	Are the defects in the rejected garments easily traceable by common people?	Are the rejected garments wearable after some rework?	Is there any specific guideline from buyers for the management of rejected garments?	Do manufacturers do some rework on rejected garments before selling to others than buyers?	What do the manufacturers usually do with the rejected garments?
F1	Yes	No	Most of them are not easily traceable	Most of them are wearable & other are not	No specific guideline	Always	Sell locally at lower price
F2	Yes	No	Most of them are not easily traceable	Most of them are wearable & other are not	Store it for definite period and then sell	Not necessary	Sell locally at lower price
F3	Yes	Yes	Most of them are not easily traceable	Most of them are wearable & other are not	Store it for definite period and then sell	Sometimes	Sell locally at lower price
F4	Yes	Yes	Yes	Most of them are wearable & other are not	No specific guideline	Sometimes	Sell locally at lower price

Table 3 continued

F5	Yes	No	Most of them are not easily traceable	Most of them are wearable & other are not	Destroy	Not necessary	Destroy the rejected garments
F6	No	No	Most of them are not easily traceable	Most of them are wearable & other are not	No specific guideline	Not necessary	Sell locally at lower price
F7	Yes	Yes	Yes	Most of them are wearable & other are not	Store it for definite period and then sell	Sometimes	Sell locally at lower price
F8	Yes	No	Most of them are not easily traceable	Most of them are wearable & other are not	Store it for definite period and then sell	Sometimes	Sell locally at lower price
F9	Yes	No	Most of them are not easily traceable	Most of them are wearable & other are not	Destroy	Not necessary	Destroy the rejected garments
F10	Yes	No	Yes	Most of them are wearable & other are not	Destroy	Not necessary	Destroy the rejected garments
F11	Yes	Yes	Yes	Most of them are wearable & other are not	Store it for definite period and then sell	Always	Sell locally at lower price
F12	No	No	Most of them are not easily traceable	Most of them are wearable & other are not	No specific guideline	Always	Sell locally at lower price
F13	No	No	Most of them are not easily traceable	Most of them are wearable & other are not	No specific guideline	Sometimes	Sell locally at lower price
F14	No	No	Most of them are not easily traceable	Most of them are wearable & other are not	Store it for definite period and then sell	Not necessary	Sell locally at lower price
F15	Yes	No	Most of the defects are not traceable	Most of them are wearable & other are not	Store it for definite period and then sell	Sometimes	Sell locally at lower price
F16	Yes	Yes	Yes	Most of them are wearable & other are not	No specific guideline	Always	Sell locally at lower price
F17	Yes	No	Most of them are not easily traceable	Most of them are wearable & other are not	Sell them anywhere	Sometimes	Sell locally at lower price
F18	Yes	No	Yes	Most of them are wearable & other are not	No specific guideline	Not necessary	Sell locally at lower price

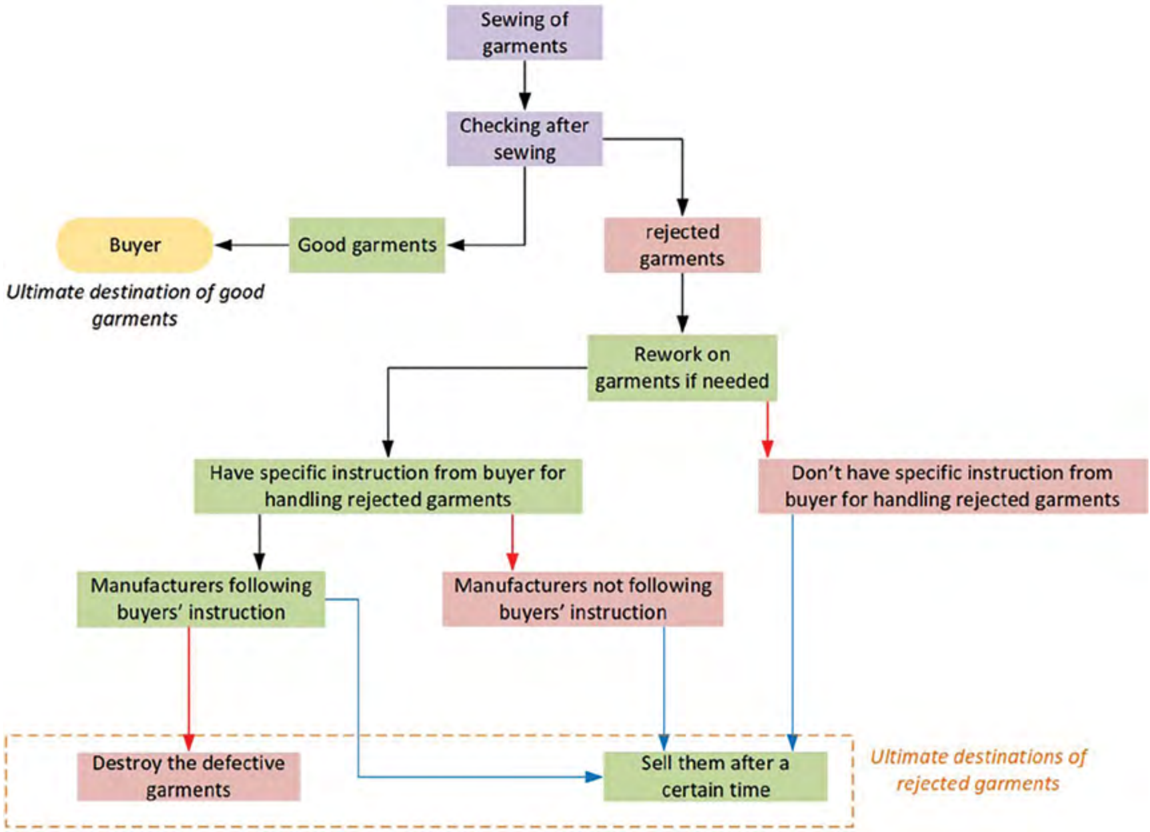

Figure 1: Model for present scenario of rejected garments management in Bangladesh

In order to transform the world and make it a better place for future generations, the General Assembly of United States declared 17 SDGs as a way of bringing prosperity to the world. Among these 17 goals, SDG 12 focuses on responsible consumption and production. Research has shown that high-income countries have a greater environmental footprint than low-income countries in terms of consumption. One study showed that to achieve the SDG 12 policy, such as a proper waste management strategy, the use of eco-friendly raw materials, recycling, reuse and extended lifetime use could be adopted [20]. Figure 2 represents the proposed model to mitigate the current problem.

The existing model for the management of rejected garments (Figure 1) shows that there are ultimately two destinations for such garments, i.e. local market and destruction, while the new proposed model shows that if proper policy can be adopted by mutual understanding between buyers and manufacturers, there are scopes where rejected garments can be exported to buyers as well. Another important point is that in the current model, manufacturers have no clear instructions to sell second-quality garments in the local market. However, for long-term business, proper guidelines should be introduced. The interview data show that buyers are pushing manufacturers for sustainability. Hence, the authors believe that to foster sustainable consumption and do business in a sustainable way, proper guidelines or permission should be given to manufacturers for the garment to stay for a longer period in our consumption system. Even in such cases, fixing the garments is not possible if there are too many defects or some kind of a major defect. In that extreme case, recycling the materials without destroying them can be a sustainable approach. Recycling can also help minimise the dependency on virgin materials. However, the problem is that the setup of recycling is costly and not every factory can afford it. The possible solution could be that

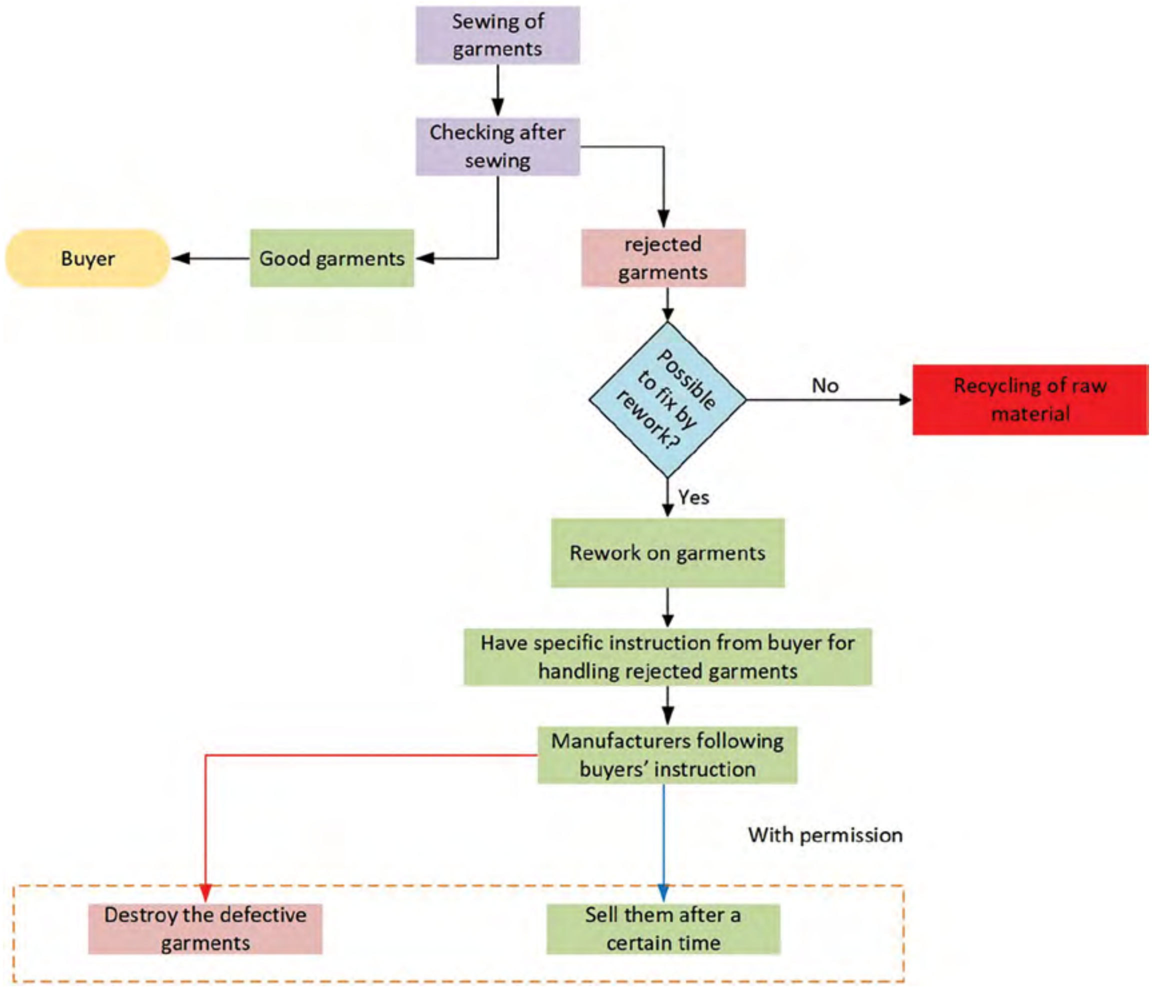

Figure 2: Proposed model to mitigate current problem

manufactures who have an existing recycling setup can collect or purchase rejected garments from other manufacturers who do not have recycling facilities and recycle them.

The proposed model and policy will benefit manufacturers, manufacturers, consumers, buyers and the environment. From the manufacturers' point of view, the proposed model will encourage them to capture money either by selling to buyers, other international second-hand markets or even in local markets in a legal way. The policy of selling the rejected garments also ensures that no rejected garments are piled up in the manufacturing country, which will be considered waste. Since many defects in the rejected garments are not seen in common people's eyes, there is less chance that those defects will hamper the overall look of the garments. Thus, consumers can obtain fashionable products at a lower price. Recently, consumers have been becoming conscious enough to think about the impact of textiles on the environment. The second category of products can contribute to the environmentally conscious buying behaviour of consumers. Renowned clothing brands advertise themselves by claiming the sustainable use of eco-friendly materials and processes. Selling second-category garments in their branded shops can open new opportunities to contribute more to the sustainability of the clothing business. Finally, if clothing is allowed to stay in the consumer cycle for a longer period, this will put less pressure on using new raw materials and energy. All of these factors will contribute to obtaining the SDG 12 goal.

4 Conclusion

Rejected items are a part of every manufacturing activity. The export-oriented clothing manufacturing factories in Bangladesh produce high quality goods and also some rejected garments as it is almost impossible to design a manufacturing system that will not yield any rejection which will eventually become waste. However, not all rejected garments are wasted. Garments carrying minor defects have a market. These second category markets are for people who have a relatively low income or who are conscious of sustainability. In the garment export business, buyers are always in the driving seat for implementing new strategies, e.g. adopting sustainable means. The rejected garments produced at the manufacturing points are one kind of waste. Nevertheless, there is no concrete strategy to manage these rejected garments by the manufacturers or even proper guidelines from the buyers, who are actually the policymakers. This study reflects the current business scenario of the Bangladeshi clothing industry in terms of rejected garment management and also provides an alternative solution in which a mutually collaborative approach will help conduct the business in a more sustainable way. This study feels the need for a proper policy; however, it has not stated the factors that should be considered during policymaking in detail, which opens up an opportunity for future research. To overcome this situation, the willingness of the government, exporters and importers is also an issue, and the situation should not be overlooked.

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Influence of Textile Substrates on the Adhesion of PJM-Printed MED610 and Surface Morphology

Vpliv tekstilnega substrata na adhezijo smole MED610, natisnjene s tehniko kapljičnega nanašanja PJM, in morfologija površine

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Abstract

The idea of 3D printing on textile fabrics was first mentioned around 10 years ago and has been investigated in detail since. Originally aimed at opening new design possibilities, combining 3D printing with textile substrates has shifted towards a new method to prepare composites with defined mechanical and other physical properties. The main problem of fused deposition modelling (FDM; also referred to as material extrusion (MEX) according to ISO/ASTM 52900) is printing on textile fabrics, where the frequently insufficient adhesion between both materials has not been fully resolved. For this reason, a few attempts have been made to combine other additive manufacturing methods with textile fabrics. While the principle possibility of using stereolithography (SLA) on textile fabrics was demonstrated a few years ago, PolyJet modelling (PJM) has only recently proven to be applicable for direct printing on textile materials. Here, we present the first study of printing MED610 medical resin on different fabrics. We show that a higher textile fabric surface roughness generally increases the adhesion of the printed material, while a higher hydrophobicity is disadvantageous. We also tested the influence of textile substrates on the porosity of the MED610 surface, as this parameter can influence a material's potential use in tissue engineering and other biomedical applications.
Keywords: material extrusion, MEX, adhesion, fused deposition modelling, FDM

Izvleček

Ideja o 3-D tiskanju na tekstil je bila prvič omenjena pred približno desetimi leti in je bila od takrat podrobno raziskana. Kombinacija 3-D tiskanja s tekstilnimi materiali, ki je bila prvotno namenjena odpiranju novih možnosti oblikovanja, se je pozneje preusmerila na nove metode za pripravo kompozitov z definiranimi mehanskimi in drugimi fizikalnimi lastnostmi. Glavna težava modeliranja taljenega nanašanja (FDM; imenovana tudi ekstruzija materiala (MEX) v skladu z ISO/ASTM 52900) je tiskanje na tekstilije, kjer pomanjkljivost nezadostne adhezije med obema materialoma

še ni bila v celoti odpravljena. Zato je bilo narejenih nekaj poskusov kombiniranja drugih metod aditivne tehnologije s tekstilijami. Medtem ko je bila glavna možnost uporabe stereolitografije (SLA) na tekstilijah prikazana pred nekaj leti, se je modeliranje PolyJet (PJM) izkazalo za uporabno za neposredno tiskanje na tekstilne materiale šele pred kratkim. V tem članku je predstavljena prva študija tiskanja medicinske smole MED610 na različne tkanine. Dokazano je, da na povečanje adhezije natisnjenega materiala vpliva večja površinska hrapavost tekstilije, medtem ko večja hidrofobnost to adhezijo poslabša. Preizkušen je bil tudi vpliv tekstilnih materialov na poroznost površine MED610, saj lahko ta parameter vpliva na potencialno uporabo materiala v tkivnem inženirstvu in drugih biomedicinskih aplikacijah.
Ključne besede: ekstrudiranje materiala, MEX, adhezija, modeliranje taljenega nanosa, FDM

1 Introduction

In the last decade, additive manufacturing has developed further from a tool for rapid prototyping towards the possibility of the rapid production of unique parts that frequently could not be produced using other techniques. The fused deposition modelling FDM (or material extrusion, MEX) printing process is used most, and is based on inexpensive machines and polymer materials [1]. Stereolithography (SLA), the very first 3D printing technique, is also widely used today [2]. There are, however, many more additive manufacturing techniques available, which facilitate the printing of diverse polymers, metal and various blends with different accuracies [3–5].

Representing one of the main problems of 3D printed objects, in addition to frequently insufficient dimensional accuracy, are mechanical properties, which are often diminished in comparison with injection moulded objects due to the layer-wise build-up [6, 7]. Different possibilities have been suggested to improve tensile and bending properties, such as thermal post-treatment [8,9], the integration of fibrous or other fillers in the printed polymer [10, 11] or the optimization of printing parameters [12, 13]. A completely different approach is given by combining 3D printing, especially FDM printing, with a textile fabric to form a composite with improved lateral mechanical properties.

In this approach, the main problem is the adhesion between the textile substrate and the imprinted polymer [14–16]. This topic has been investigated in detail by several research groups in the last decade, revealing several parameters that influence adhesion in the case of FDM printing on textile fabrics, such as extrusion temperature and printing speed [17], the surface structure of the fabrics, as well as the mass per unit area and thickness thereof [18–20]. While a thermal after-treatment of the composite was only found to have a positive impact in some experiments [21, 22], the chemical pretreatment of the textile fabric to reduce hydrophobicity was reported to be advantageous in many cases [22–24]. Most importantly, the z-distance between nozzle and fabric must be tailored carefully to press the FDM polymer sufficiently deep into the textile fabric to reach a form-locking connection, while avoiding the clogging of the nozzle [25, 26].

The latter point is different when SLA or other resin-based 3D printing techniques are applied to print on textile fabrics. On the one hand, SLA resins are significantly less viscous than the molten polymers used in FDM printing, making it easier for them to penetrate through the fabric and build a form-locking connection [27]. On the other hand, pressing the resin into the fabric is usually not possible in resin-based printing processes.

While the possibility of performing SLA printing on textile fabrics was already reported in 2020, PolyJet modelling (PJM) on textile fabrics was only shown recently for the first time [28]. This method has the advantage of not inserting the whole fabric into the resin, as is necessary in SLA printing; instead the resin is only placed at the desired positions [28].

Here, we extended the first proof-of-principle of PJM printing on textiles by using another resin, MED610, which is mainly used in medicine and dentistry [29], to increase the potential range of applications and avoid potentially toxic materials. Different woven fabrics are tested to investigate the influence of textile surface roughness on adhesion, and to test whether the Korger rule [30], stating that hydrophilic textiles enable a higher adhesion than hydrophobic ones, also holds true for PJM printing. Finally, the potential influence of a textile substrate on the surface porosity of the MED610 surface was investigated, as this parameter plays an important role in tissue engineering and other biomedical applications in which MED610/textile composites may be used [31–33].

2 Materials and methods

Two different sets of textiles were tested in this study. The first set consisted of three woven fabrics from cotton (thickness 0.34 mm, mass per unit area 143 g/m²), linen (0.54 mm, 196 g/m²), and polyester (PES) "micropeach", which is roughened on one side (0.38 mm, 127 g/m²). All three textiles were also investigated in [28] and were found suitable for PJM printing using Fullcure720 PJM resin. The second set of samples contained PES woven fabrics in plain weave (thickness 0.32 mm, mass per unit area 167 g/m²), twill weave 2/1 (0.32 mm, 186 g/m²), and Leno (0.48 mm, 181 g/m²). These three samples were recently investigated in terms of FDM and SLA printing [34], and thus allow for a direct comparison of two resin-based printing methods, although with different resins according to the limited availability of materials for both printing methods.

3D printing was performed with the aforementioned MED610 medical resin (Stratasys, Eden Prairie, MN, USA), certified as biocompatible material according to ISO 10993-1:2009 [35,36]. A Connex 350 PJM printer (Stratasys) was used to prepare rectangular samples (n = 3) for adhesion tests according to DIN 53530, which were evaluated according to DIN ISO 6133. These adhesion tests were performed using a Sauter FH2K universal test machine. Confocal laser scanning microscope (CLSM) images were taken using a VK-8710 (Keyence, Neu-Isenburg, Germany) and evaluated using ImageJ 1.53e software (National Institutes of Health, Bethesda, MD, USA). Water contact angles were measured at a magnification of 5x using a USB microscope.

3 Results and discussion

While the water contact angle of the front side of the PES "micropeach" fabric (on which printing was performed) was measured as (123 ± 6)°, all other materials were highly hydrophilic, with water drops spreading very fast in the other three (untreated) PES fabrics and the linen fabric, and spreading slower in the cotton fabric. According to the Korger rule, this leads to the first assumption that the adhesion should be highest on linen and the untreated PES fabrics and lowest on the PES "micropeach" [22, 23].

Indeed, the adhesion tests revealed the highest adhesion forces for MED610 on linen, as the exemplary measurement curves in Figure 1a show. Here it can also be seen that the curve measured for MED610 on linen varies more than the others, while the adhesion on PES micropeach varies only slightly. This can be attributed to the different surface morphologies, as will be discussed later.

This means that different evaluation methods according to ISO 6133 must be used for cotton, linen and Leno on the one hand (procedure C, for graphs with more than 20 peaks) and for the PES micropeach, PES plain weave and twill on the other hand (procedure D, for wavy curves). This must be taken into account in the discussion of adhesion values.

Interestingly, the adhesion values of MED610 on plain weave and twill are relatively low (Figure 1b), while the values on the thicker Leno fabric are similar to those found on the cotton fabric. The adhesion on the Leno fabric was even high enough to destroy two of the three fabrics during the adhesion tests. Here, apparently not the hydrophobicity, but

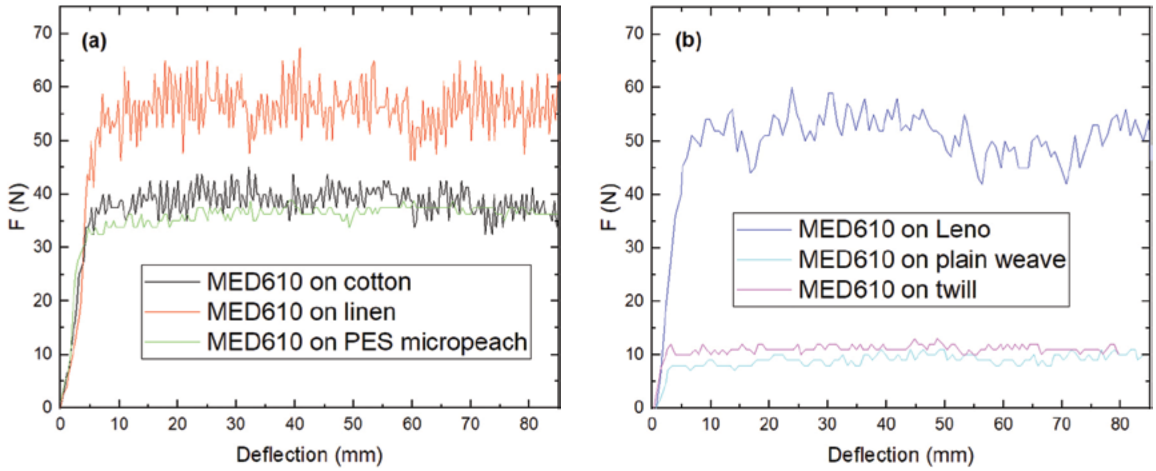

Figure 1: Exemplary adhesion test curves of MED610 on (a) cotton, linen and PES micropeach, (b) polyester plain weave, twill weave and Leno fabric.

the thickness of the fabric plays an important role, as both the thickest fabrics (linen and PES Leno) show clearly higher adhesion than the other woven fabrics. The low adhesion values of the PES plain weave and twill weave fabrics, on the other hand, can be explained by their dense woven structure without large air voids, as can be seen by comparing their apparent densities (calculated as the mass per fabric volume) or the corresponding porosities (calculated from a comparison of the apparent density with the respective material's bulk density, using literature values of 1.5 g/cm³ for PES, 1.51 g/cm³ for cotton and 1.4 g/cm³ for linen).

Table 1 gives an overview of the parameters that can initially be deemed to have an influence on adhesion, with the colours ranging from green (positive impacts) to red (negative impacts). According to this table, both PES plain and twill weave should show the lowest adhesion, followed by PES micropeach and cotton, while linen and the Leno fabric should have the highest adhesion. This corresponds to the findings of Figure 1.

Table 1: Colour-coded influence of different parameters on the adhesion on the tested woven fabrics

Sample	Hydrophobicity	Thickness (mm)	Apparent density (kg/m³)	Porosity (%)
PES "micropeach"	Hydrophobic	0.38	334	78
Cotton	Hydrophilic	0.34	421	72
Linen	Hydrophilic	0.54	363	74
PES plain weave	Hydrophilic	0.32	522	65
PES twill 2/1	Hydrophilic	0.32	581	61
PES Leno	Hydrophilic	0.48	377	75

The evaluation of the adhesion tests and a comparison with previous tests on the same materials are shown in Figure 2. First, when comparing the adhesion values for MED610 on the different woven fabrics, it is obvious that the adhesion on linen is highest, as expected from Figure 1, followed by PES Leno. Comparing the adhesion of MED610 on cotton and PES micropeach, the calculated value for the latter is significantly lower according to Figure 2, while both were similar in Figure 1. This can be explained by the aforementioned different evaluation methods, leading to the average of all adhesion values of PES micropeach, while only peaks were counted for cotton and linen.

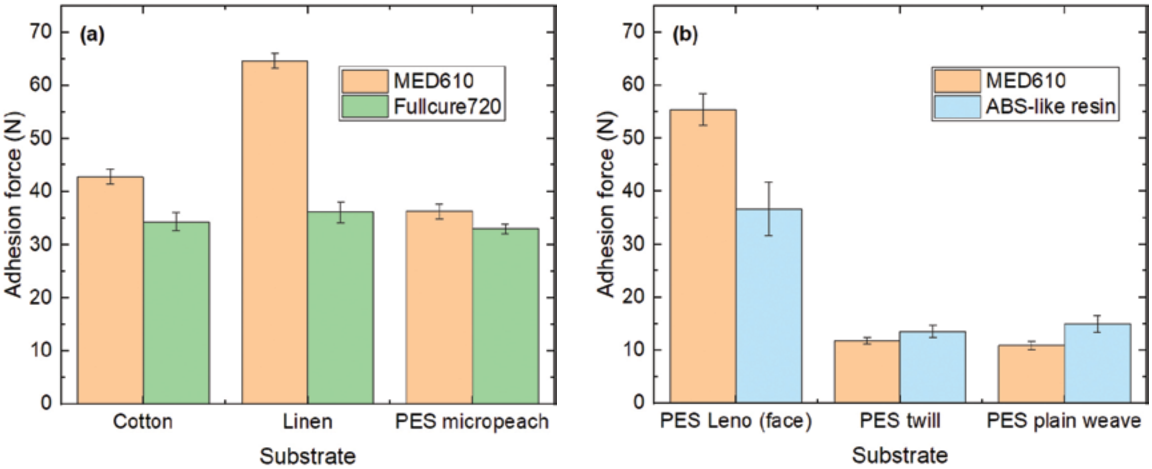

Figure 2: (a) Comparison of the adhesion of MED610 (new values) and Fullcure720 (values from [28]) on cotton, linen and PES micropeach; (b) comparison of the adhesion of MED610 printed with PJM (new values) with the adhesion of "ABS-like resin" printed using SLA (values from [31]).

Most interestingly, especially for linen, the adhesion could be significantly increased compared to the previous measurement with Fullcure720 [28]. While both resins have a similar viscosity and can thus be expected to flow into the textile materials in a similar way, the recent printing processes were performed by carefully calculating the z-position of the first printed layer according to the textile thickness. It can thus be speculated that optimizing the z-position of the PJM printed material can also be used to improve the adhesion on a textile fabric, similar to the necessary optimization of the z-distance between nozzle and printing bed for FDM printing on textile fabrics [25, 26]. While this optimization process was not developed further in this study, it will be investigated further in the near future.

Comparing the resin-based methods FDM and SLA printing (Figure 2b), the values for the thinner fabrics are quite similar, while the Leno fabric revealed a higher adhesion for PJM, indicating that this technique may be advantageous for thicker fabrics. However, a larger study comparing these techniques is necessary to reveal all their advantages and disadvantages.

Besides the hydrophobic/hydrophilic properties of textile substrates, their thickness and apparent density (cf. Table 1), their surface structure can also be expected to influence adhesion. Figure 3 depicts CLSM images of the back of the MED610 printed material after the adhesion tests on the first set of samples, showing the surface morphology (left panels) as well as the colour-coded heights (right panel). For all three textile fabrics, the woven structure is clearly visible, showing how precisely the low-viscous resin follows the textile surface during printing. This is a clear advantage of PJM printing over FDM printing. In addition, there are differences visible between cotton (showing a few protruding fibres, visible as red-orange colours), linen (showing many more fibres), and PES micropeach (without fibres). A larger number of fibres can also be expected to support adhesion, as would be the case for FDM printing.

After the investigation of the adhesion between MED610 and the different fabrics, the potential influence of the textile substrates on the MED610 surface was examined for the first set of samples. This is especially important for this resin due to its potential use in biomedical applications, where the growth of mammalian cells, for example, is strongly influenced by surface porosity. An initial comparison of the surfaces of MED610 printed purely on the printing bed and printed on the different textiles, respectively, is shown in Figure 4. Nine more images of each set of samples are shown in the appendix.

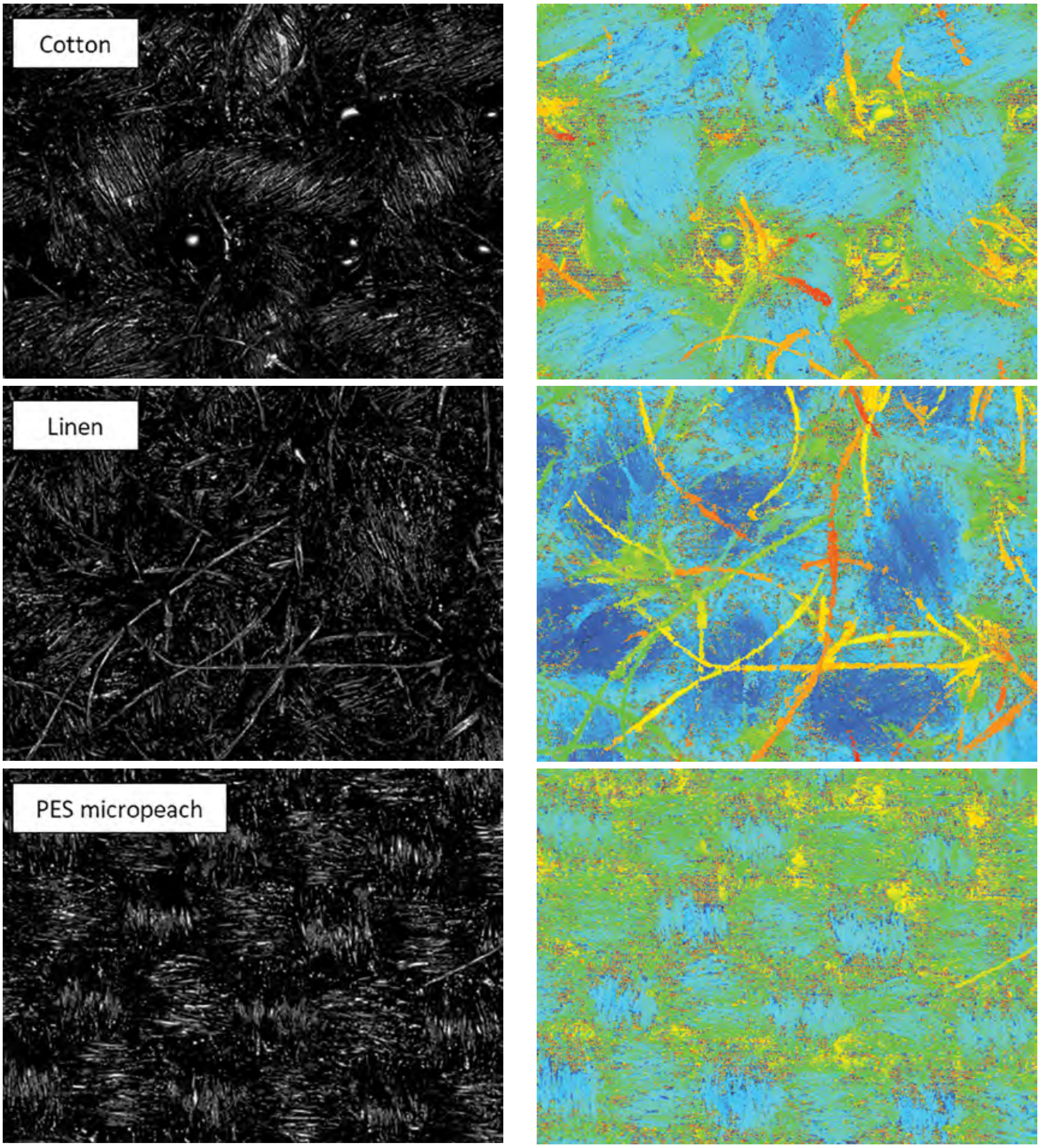

Figure 3: CLSM images on the back of MED610 detached from different textile fabrics, showing the optical appearance (left panels) and the heights (right panels). In the latter, blue shows the lowest areas and red the highest areas. Images sizes correspond to 1.4 mm × 1.05 mm.

The first optical impression of these images is that there are more "large" holes visible on the surface of the pure MED610, while printing on textile fabrics leads to more small holes. However, this first impression should be quantified, taking into account a larger number of CLSM images. For this reason, additional images at three positions of each of the three samples were taken (cf. appendix). Next, a procedure had to be defined to quantitatively evaluate the numbers of small and large holes in these images.

Used for this purpose was the ImageJ software, which can count particles in an image. The following process was followed to set the colour threshold and to count the particles:

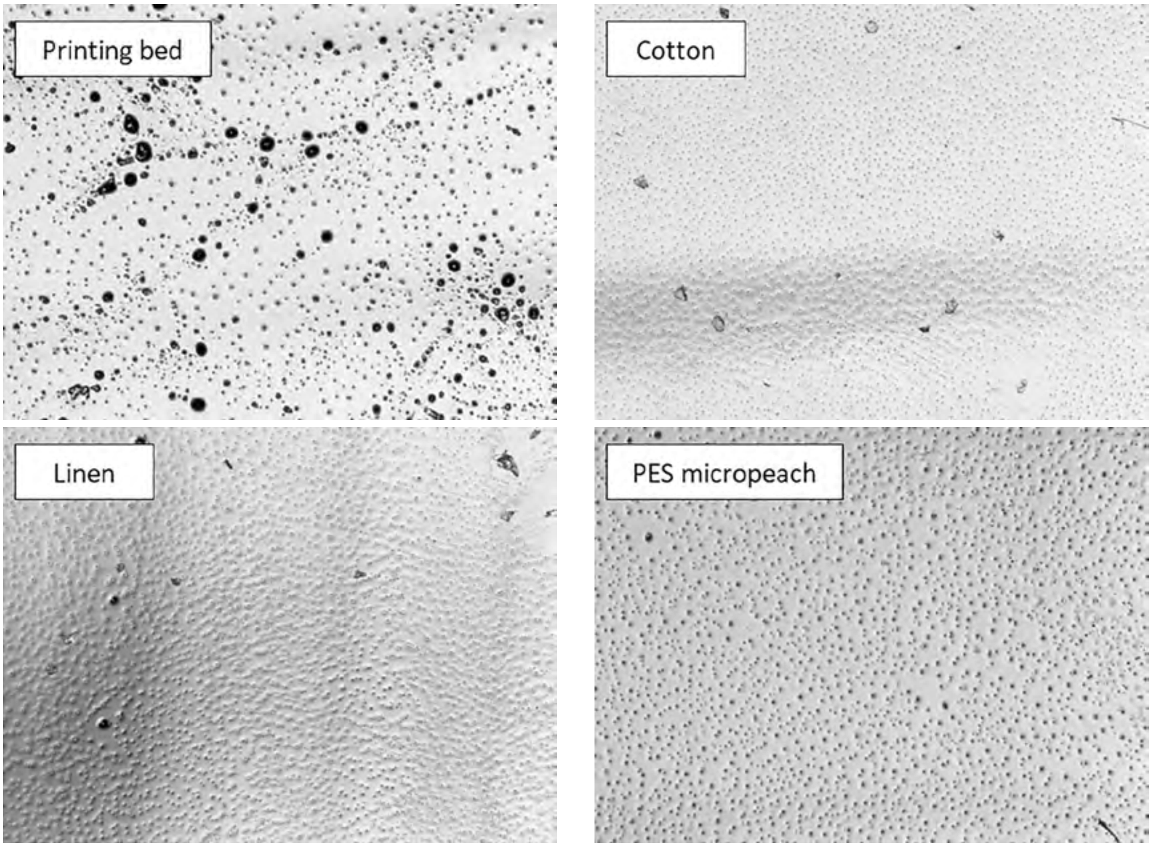

Figure 4: CLSM images of the surfaces of MED610 printed on the usual printing bed and different textile fabrics, respectively. Images sizes correspond to 1.4 mm × 1.05 mm.

- Image → Adjust → Colour threshold
- Analyse→ Analyse particles

The following definitions were chosen for this paper:

- A threshold area of 400 pixels was chosen for "small" holes. The image size of 2048 x 1536 pixels corresponds to 1.4 mm x 1.05 mm, so that a 400-pixel area (i.e. a hole diameter of 22.5 pixels) corresponds to 15.4 µm. This value was chosen as typical mammalian cells have diameters of around 10 µm, so that a slightly larger hole size may be supportive for mammalian cell adhesion and proliferation.
- The "larger" holes were further subdivided into "irregular" (circularity 0.00-0.07) and "round" holes (circularity 0.71-1.00), where the cut-off for the circularity was subjectively chosen. All "large" holes were manually checked to avoid misinterpretations due to an inappropriate colour threshold.

It should be mentioned that these values can naturally be chosen in any other way; these values were used as a first approach to quantify the apparent optical differences between different surfaces. The results are presented in Figure 5.

Generally, Figure 5 shows a slight tendency towards smaller numbers of small and large holes on linen, and larger numbers on pure MED610, but no significant differences are visible, as the very large error bars show. An optical investigation of the CLSM images in the appendix reveals a similar finding: large differences occur between different samples of the same material combinations, e.g. comparing samples S1 and S2 in Figure A2 with

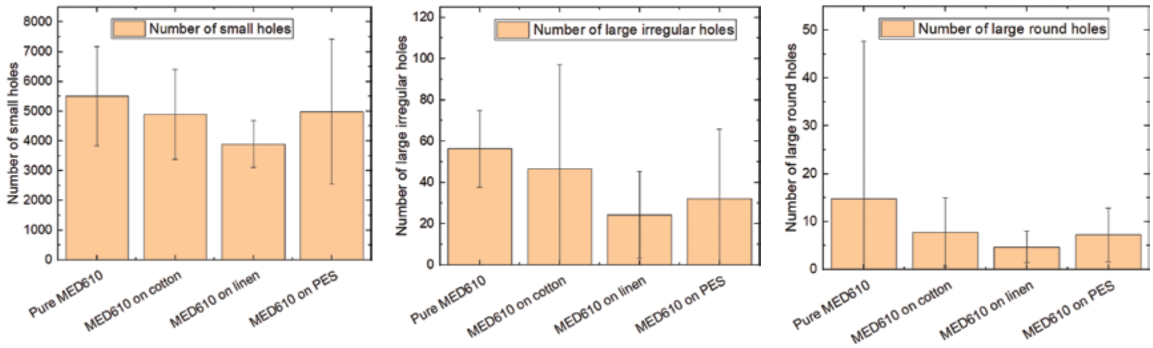

Figure 5: Numbers of small, large irregular, and large round holes on MED610 surfaces, counted with the above described process on ten CLSM images per material combination.

sample S3, and even comparing different positions on one sample, e.g. positions P2 and P3 of sample S1 in Figure A4. On the other hand, the optically most homogeneous surface with the fewest large holes can all be found for MED610 printed on cotton or linen fabrics (Figure A2, A3), suggesting that the potential influence of printing on textile fabrics on the MED610 surface should be investigated further, although the quantitative analysis of the holes in the surface did not reveal significant differences.

Finally, it should be mentioned that the chosen method here, applying an automatic cut-off value for brightness in order to separate holes from the surrounding area, shows very different stability against variations of this cut-off value for different images. As an example, Figure 6 shows for two images on the same MED610 sample on cotton (cf. Figure A2), taken on different spots of the sample surface (positions P1 and P2 on sample S1), the numbers of small holes counted for different brightness cut-offs. While for position P1 (black dots), the automatically set brightness cut-off value leads to a number of small holes near the maximum that can be reached by varying the cut-off value, this is completely different for position P2 on the same sample (red dots). As these examples show, the brightness cut-off value can strongly influence the number of counted small holes, making this value highly unreliable. This investigation was thus not repeated for the second set of samples.

The results showed that a pragmatic evaluation based on a threshold value does not lead to stable and reliable statements. For further investigations, other image evaluation algorithms should be used for a reliable analysis of the image data. For image data that has overall homogeneous grey value data, the threshold value could be adjusted by evaluating the histogram data of an image. If the grey values within an image fluctuate considerably, gradient filters or other approaches from image preprocessing could be used. The use of neural networks for object detection, such as the Segment Anything Model (SAM) from Meta AI, should also be considered. Further investigations of the image data should follow from this.

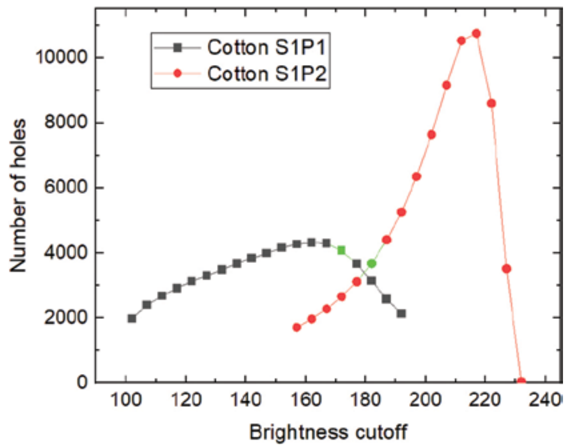

Figure 6: Numbers of small holes on MED610 on cotton, counted on two positions of the same sample (cf. Figure A2), depending on the brightness cut-off. The green dots correspond to the automatically set brightness cut-off values.

4 Conclusion and outlook

MED610 medical resin was PJM-printed on different textile fabrics. The highest adhesion values were found for the most hydrophilic and hairy linen woven fabric, as expected, directly followed by a PES Leno fabric with similarly low apparent density and relatively high fabric thickness. For the first set of samples, adhesion could be increased compared to a previous study using Fullcure720 [28], which can be attributed to the better setting of the first layer z-position. For the second set of samples, similar values were found as in a previous study on SLA printing on these materials [31]. In addition, CLSM images revealed a tendency towards a more homogeneous surface with fewer large holes when printing especially on linen woven fabric, which may support the use of MED610 in tissue engineering and other potential applications.

Generally, a good adhesion could be correlated with relatively thick, hydrophilic fabrics with a low apparent density. Both the dependence of adhesion on the setting for the first layer z-position and the influence of different substrates on the surface morphology will be further investigated in a subsequent study aimed at providing reliable rules for optimized PJM printing on textile fabrics.

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Appendix

CLSM images taken at three positions (P1, P2, P3) of three samples (S1, S2, S3) per material combination

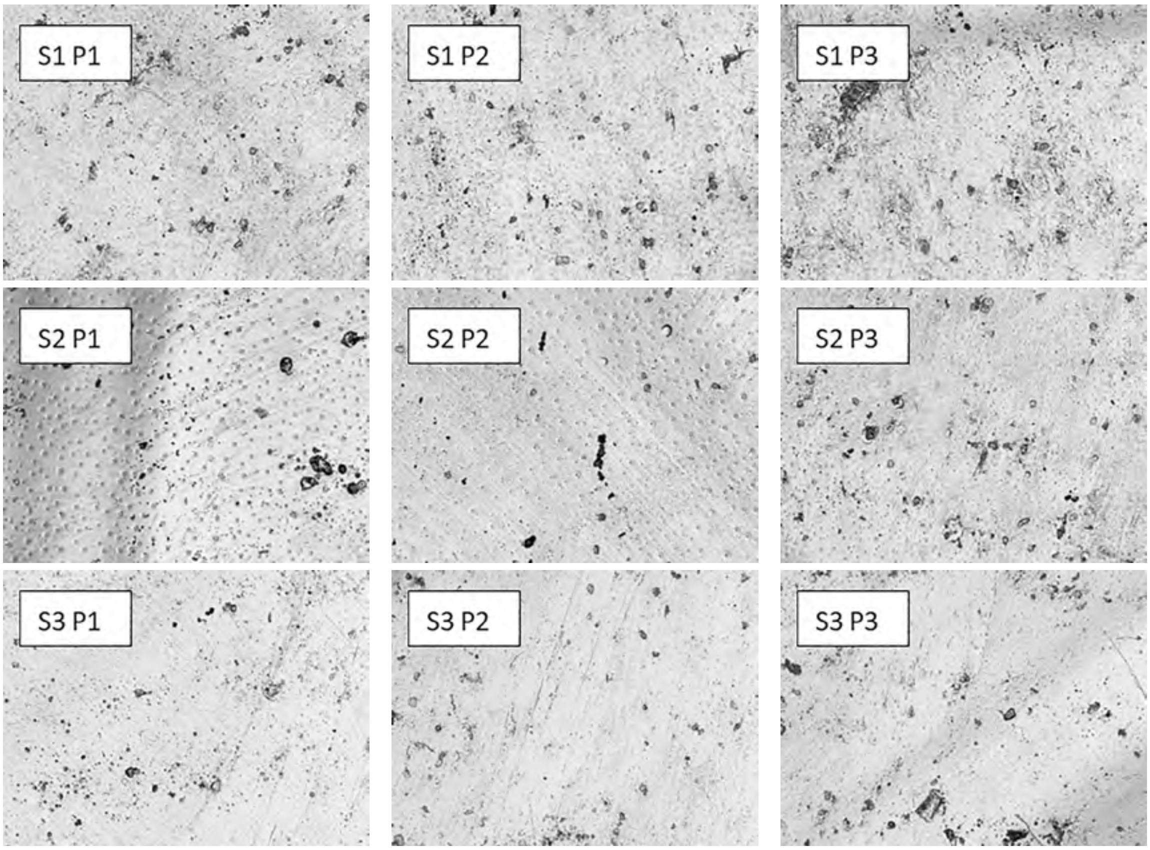
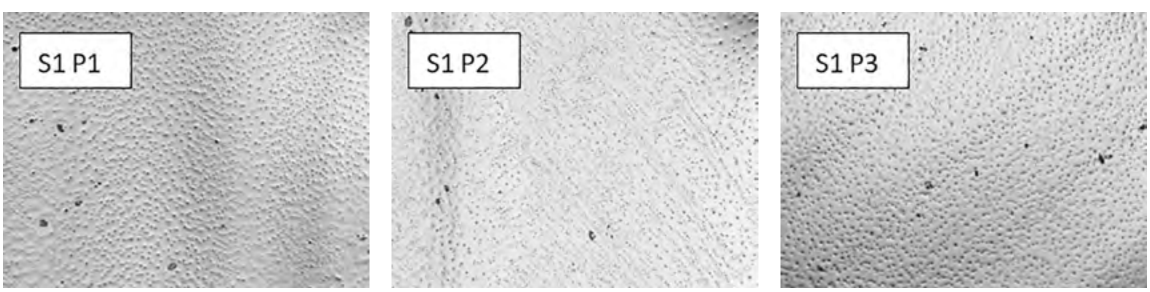


Figure A1: CLSM images on pure MED610 samples. Images sizes correspond to 1.4 mm x 1.05 mm.



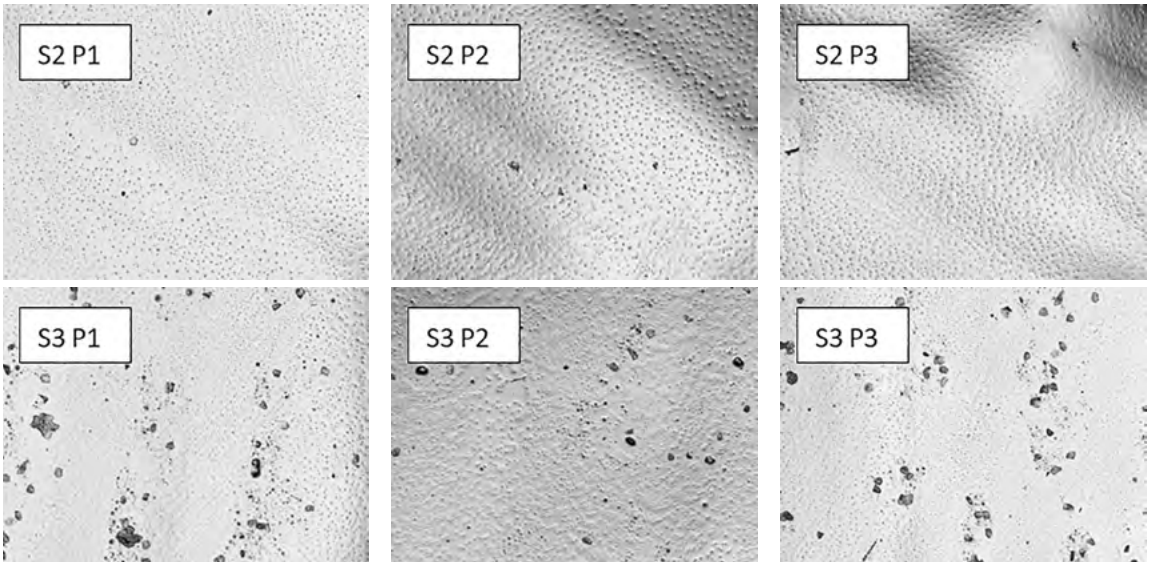


Figure A2: CLSM images on MED610 on cotton. Images sizes correspond to 1.4 mm x 1.05 mm.

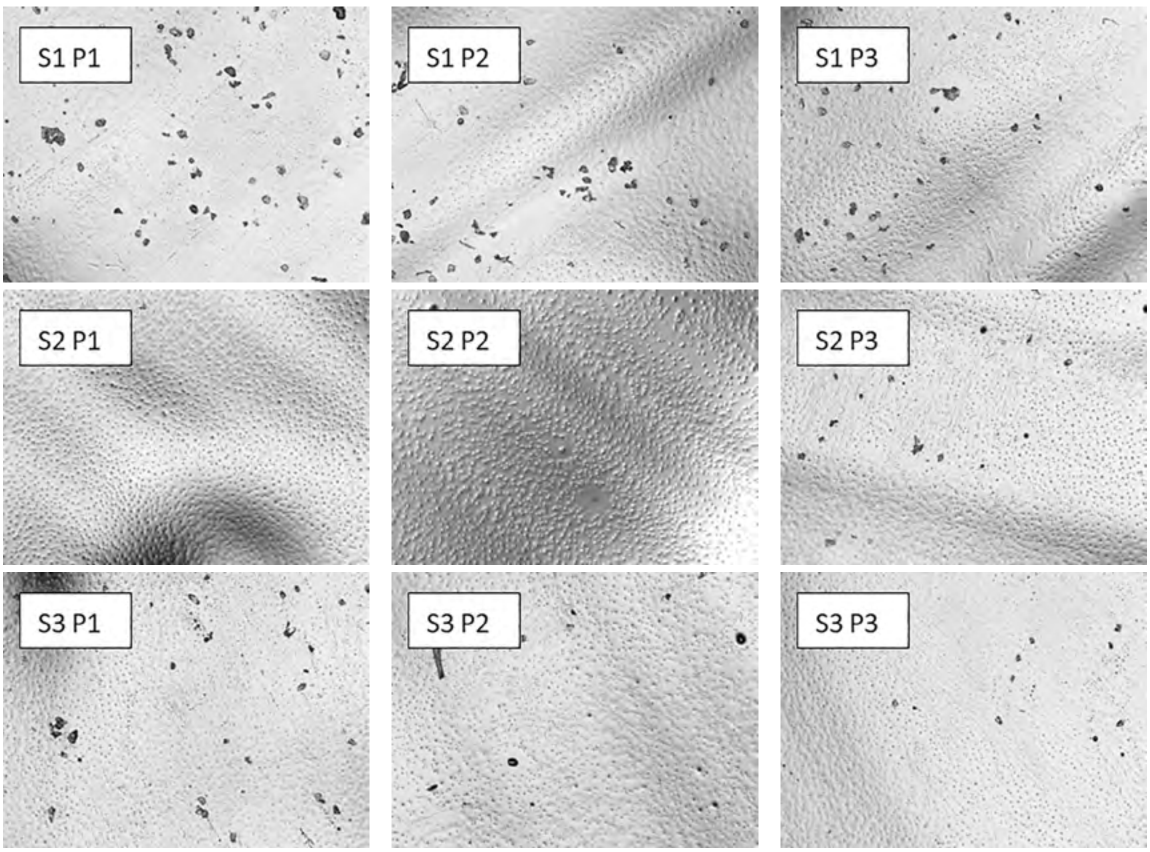


Figure A3: CLSM images on MED610 on linen. Images sizes correspond to 1.4 mm x 1.05 mm.

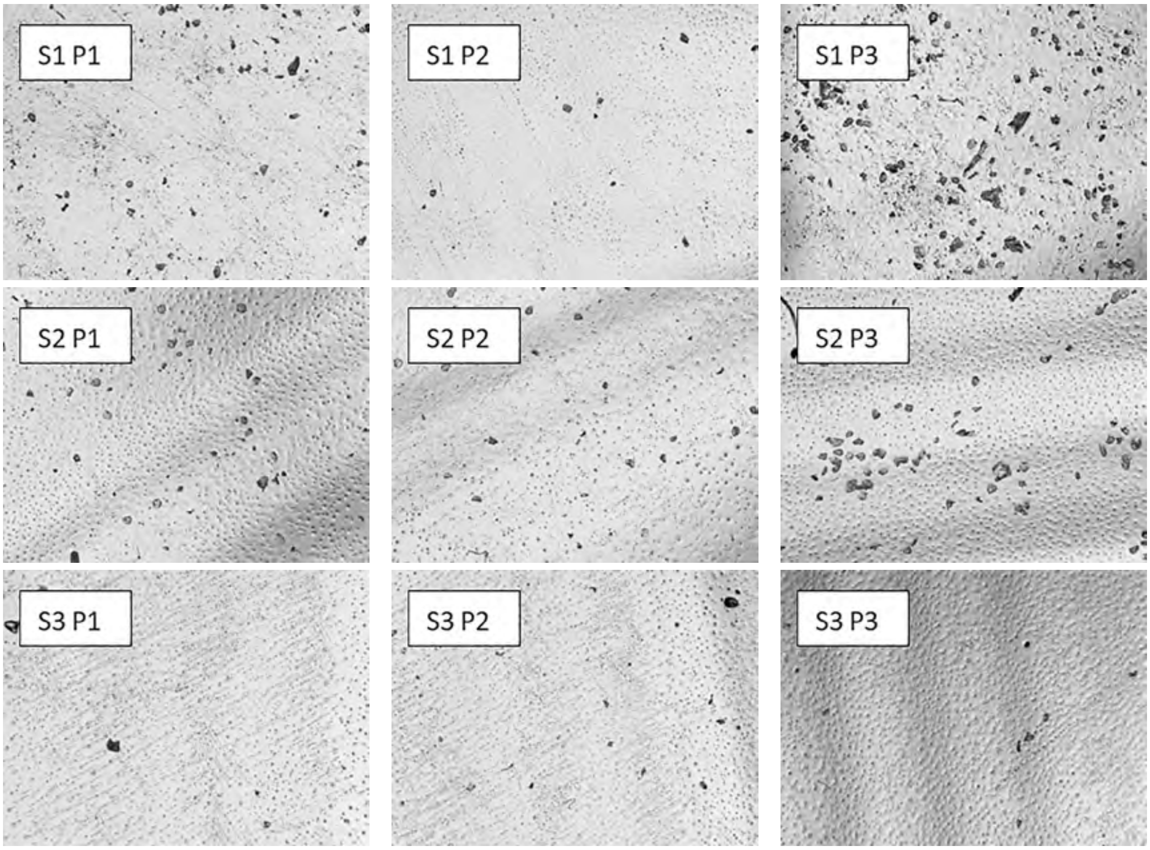


Figure A4: CLSM images on MED610 on polyester "micropeach". Images sizes correspond to 1.4 mm x 1.05 mm.

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Development of Laminated Knitted Fabrics with Improved Performance Properties for Automotive Upholstery

Izboljšanje uporabnih lastnosti laminiranih pletiv za oblazinjenje avtomobilskih sedežev

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Abstract

The aim of this study was to develop car seat fabrics with better thermal properties than the conventional automotive upholstery fabrics currently used in cars. For this purpose, knitted fabrics were produced using three different special polyester yarns, with high thermal properties and produced in three different fabric structures, to determine the effects of material type and fabric structure. Conventional polyester yarn was also used for comparison purposes. In order to examine the performance properties of the upholstery fabrics in real conditions, the fabrics were laminated with foam and scrim. The automotive upholstery laminated fabrics were then tested for various performance and thermal properties. The results revealed that all samples met the requirements of automotive upholstery performance tests. In addition, the laminated fabric knitted with Type C yarn using an eyelet-12 structure demonstrated the best thermal properties. This laminated fabric could be suggested for car seats due to its higher thermal conductivity, higher air permeability, good water vapour permeability, and lighter, thinner structure.

Keywords: automotive upholstery, thermal comfort, performance properties, flammability test

Izvleček

Namen raziskave je bil razviti tekstilije za oblazinjenje avtomobilskih sedežev z boljšimi uporabnimi lastnostmi od konvencionalnih, ki se danes uporabljajo v avtomobilih. V ta namen so bila iz treh specialnih multifilamentnih poliestrskih prej (Drytouch – preja A, Coolmax – preja B in Drycot – preja C) izdelana pletiva v treh različnih vezavah, da bi ugotovili vplive vrste materiala in strukture pletiva. Za primerjavo je bila uporabljena navadna poliestrska preja. Za proučevanje lastnosti pletiv za oblazinjenje v realnih razmerah so bili izdelani laminati pletivo/pena/snutkovna mreža. Laminati so bili preizkušani glede mehanskih in toplotnih lastnosti ter različnih obstojnosti. Čeprav so vsi vzorci izpolnjevali zahteve za oblazinjenje avtomobilskih sedežev, je imel laminat s pletivom iz preje tipa C v ajlet luknjičasti

strukturi 12 najboljše toplotnoizolacijske lastnosti. Ta material je med proučevanimi laminati najprimernejši za avtomobilske sedeže zaradi najvišje zračne prepustnosti in dobre prepustnosti vodne pare, pa tudi zato, ker je najlažji in najtanjši.
Ključne besede: oblazinjenje avtomobilskih sedežev, toplotno udobje, uporabne lastnosti, test vnetljivosti

1 Introduction

The amount of time vehicle occupants spend in traffic has increased significantly in recent decades. This leads manufacturers to carry out new research to improve the comfort characteristics, and the technical, mechanical and aesthetic features of vehicles [1]. One of the most important factors influencing passenger comfort is thermal comfort. The car seat acts as an extra layer of clothing, as a person sitting in a car has approximately one-quarter of their body in contact with the seat. It is therefore not enough for seats to be aesthetically pleasing or to comply with safety regulations; they must also be comfortable. Scientific studies show that if a driver's car seat does not provide adequate support for their posture and heat regulation, their long-distance driving performance will suffer significantly [2].

Car seat fabrics are made of three separate layers: face fabric, foam and scrim fabric. Each layer is bonded together through a lamination process to create a ready-to-use fabric to cover the seat. The effectiveness of each layer has a significant impact on the comfort and lifespan of a car seat. In addition to high level of physical performance, the face fabric must be aesthetically pleasing and have a porous structure for moisture and air. Polyurethane (PU) foam is known for its impermeable structure, but is preferred for its ease of use, low cost, durability and long-life. A knitted scrim fabric is used as a third layer in order to increase the slip of the ready-to-use fabric and to facilitate the seat covering process. As expected, the performance characteristics of the final car seat fabric are influenced by yarn and fabric parameters, fabric structure, thickness and layer characteristics, as well as the mechanical and chemical finishing processes applied to the fabrics [3–8]. Today, polyester yarns with high tenacity values and woven fabric structures with high stability are preferred for the face side of automotive upholstery fabrics [9–11].

Numerous studies have been conducted regarding the thermal properties of car seat covers. Armakan et. al. compared the thermal properties of unlaminated woven fabrics made from the next-generation and conventional polyester fibres. In thermal resistance tests, it was fond that fabrics made from new polyester fibres did not demonstrate any significant difference compared to fabrics made from conventional fibres. On the other hand, the water vapour permeability of fabrics made from new polyester fibres was significantly higher than the others [2]. Vois studied the effect of the cross-section of the polyester fibre on the moisture transport properties by comparing fabrics made from multi-lobed and round cross-section fibres. The results revealed that the fabric made from Dacron® multi-lobal fibre provided better moisture transport due to its unique fibre cross-section [12]. According to Pivotto and Ghiazza, automotive textiles made with Cocona® yarns, derived from coconut shells, dry their upper surfaces twice as fast as textiles made with conventional polyester [13]. Cengiz and Babalık conducted a subjective evaluation of the thermal comfort effects of ramie fibre blended yarn (RBSC) and polyester yarn-based seat covers on drivers and found that RBSC was preferred by drivers in traffic conditions [9]. Some researchers focused on the use of phase change materials (PCM) as car seat materials. These studies found that PCMs provided a cooling effect that was relatively short lasting and increasing the percentage of PCMs resulted in an increase in the thermal comfort of car seat fabrics [14–16]. Gürkan

Ünal et al. presented the comfort-related properties of the double-layered woven fabrics designed to be used in automotive seat upholstery in order to determine the effects of process parameters, such as bottom layer pattern, number of interlacing warps in a unit report, number of interlacing picks per top warp and number of weft skips. They analysed handle-related properties, circular bending rigidity, surface roughness, air permeability, thermal resistance and moisture management properties using a Taguchi experimental design [17]. Nemcokova et al. investigated the moisture management properties of the middle layer in car seat covers by using a thermography system. Knitted spacer fabric (3D spacer fabric), polyurethane foam and nonwoven fabric were used as padding in the middle layer. The distribution and transport of liquid moisture in a layered structure are significantly affected by the middle layer, in particular material composition and the value of porosity. The best moisture management characteristics were obtained from 3D spacer fabric for car seat covers [18]. In addition, some researchers have tried to replace the three-layer laminated structure with three-dimensional spacer knitted fabrics to improve thermal comfort. They found that a fabric with less thickness and more gaps in the structure demonstrates significantly higher air and water permeability [19–22].

Moisture management in a vehicle is very important to a passenger's perceived overall seating comfort. A car seat is expected to be more breathable and to provide the ideal microclimate between the driver and the seat. To achieve a dry microclimate, the seat should be able to wick perspiration away from the body quickly and easily. Water vapour permeability is expected not only in warm summer conditions but also when there is no perceptible perspiration. This is because the accumulation of moisture causes discomfort and, in some situations, the increased risk of soft tissue damage [2].

There is a wide variety of fabrics available on the market for car upholstery, and consumers choose them primarily based on the materials' aesthetic appearance, durability and mechanical performance. The aim of this study was to develop car seat fabrics with better thermal properties than the conventional upholstery fabrics currently used in cars. To this end, the study focused on knitted fabrics made with special polyester yarns and their ready-to-use forms (three-layer laminated), as opposed to the woven fabrics that are usually preferred. Three different yarns (in addition to the conventional polyester yarn) with high thermal properties and three different fabric structures were selected, in order to determine the effect of material type and fabric structure. The automotive upholstery laminated fabrics were then tested for various performance and thermal properties.

2 Materials and methods

2.1 Materials

In this study, knitted fabrics for laminating were made from different polyester yarns (Table 1) usually intended for high-thermal comfort performance. The yarn designated as Type A was made from high tech functional channel cross section fibres produced using a patented technology (Drytouch, FilSpec, CA). The result of combining advanced technology with functional results, was that the fabrics from Type A fibres have a natural look, feel softer and have better draping properties. The patented channel cross-section fibres allow it to "breathe" naturally by letting air in and moisture out, while it absorbs moisture faster than ordinary cotton fabrics [23]. The yarn designated as Type B was a four-channel polyester yarn (Coolmax, Invista, USA) that facilitates improved breathability at the expense of increased porosity between the fibres. As the surface area of the fibres increases, perspiration is removed more quickly through evaporation. Fabrics made from these yarns have a softer hand and high abrasion resistance [24]. Type C was an ultra-soft Drycot multi-filament yarn (Indorama Ventures, IT), with high natural sweat wicking to keep the body dry and antibacterial technology to improve hygiene and reduce odour. The channelled structure on the fibre surfaces allows moisture from the inside of the body to be easily transferred to the outside [25]. Conventional 100% polyester yarn was also included in the experiment plan for comparison purposes. Because automotive upholstery is subjected to extremely harsh tests, the yarns must meet specific thickness and strength requirements in order to maintain the desired physical properties. For this reason, twisted texturized yarns (twisted at 220 m^{-1}, Z-twist) were used for the face side of the laminated fabrics, and single-ply texturized yarns were used for the back side. The characteristics of the yarns are given in Table 1.

Table 1: Characteristics of the yarns used in this study

Type of yarn	Yarn code	Linear density [a] (dtex)	Linear density [b] (dtex)	Breaking force (cN)	Breaking elongation (%)
Conventional polyester	P	167/96	174	545.0	25.05
		(167/96) x 2	366	1165.2	34.00
Type A (Drytouch)	A	167/96	177	422.7	21.67
		(167/96) x 2	375	1048.0	32.12
Type B (Coolmax)	B	168/94	169	527.3	19.75
		(168/94) x 2	358	1094.2	26.57
Type C (Drycot)	C	160/77	162	553.4	21.94
		(160/77) x 2	344	1139.6	30.42

[a] declared; [b] measured

2.2 Fabric production and lamination

Fabric samples were knitted on a double bed circular knitting machine (Mayer & Cie OVJA 1.6E model with 42 feeders, E20, 26″). Three different knitted fabric structures, such as eyelet-4, eyelet-12 and pique, were used in the production of the fabric in order to study the effect of the fabric structure on the investigated parameters. The surface views taken using a Leica S8AP0 stereomicroscope at 16-x magnification and needle diagrams of the knitted structures are shown in Table 2.

All knitted fabrics were fixed on a stenter. After fixation, the fabrics were laminated with foam and scrim in the flame lamination process. The foam used in this study was based on polyester polyurethane (with a density of 26 g/m^3 and a thickness of 3.5 mm). The scrim fabric (jersey fabric; mass per unit area: 50 g/m^2) was produced using polyester yarn on a warp knitting machine. The same foam and scrim fabric were used to laminate each sample according to the same process parameters. Table 3 presents the details of the laminated fabrics.

Table 2: Needle diagram and surface views of the knitted structures

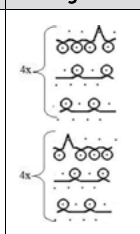
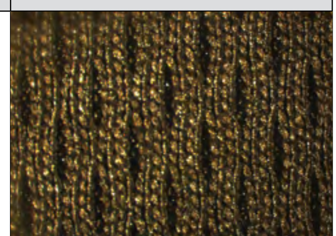
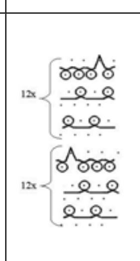
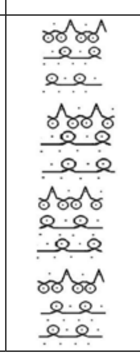
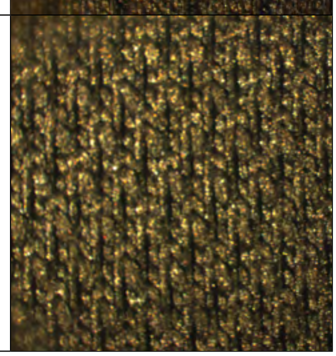
Fabric structure	Needle diagram	Surface view
Eyelet-4		
Eyelet-12		
Pique		

Table 3: Details of the laminated fabrics

Codes of laminated fabrics	Face fabric structure	Type of yarn/Linear density of yarn (dtex)/Twist (m-1) & Direction		Stitch density (yarns/cm)		Mass per unit area (g/m²)	Total thickness (mm)	Fabric density (kg/m³)
		Face side a)	Back side b)	Course	Wale			
P-P-4	Eyelet-4	P/167x2)/220Z	P/167	15.75	13.58	483.2 ± 9.68	2.86 ± 0.07	168.95
A-A-4	Eyelet-4	A/167x2/220Z	A/167	16.93	12.80	523.2 ± 13.41	2.48 ± 0.06	210.97
B-B-4	Eyelet-4	B/168x2/220Z	B/168	16.93	12.80	548.4 ± 4.08	3.26 ± 0.06	168.22
C-C-4	Eyelet-4	C/168x2/220Z	C/160	16.93	12.80	497.8 ± 3.66	2.73 ± 0.05	183.02
C-P-4	Eyelet-4	C/168x2/220Z	P/167	16.93	12.60	503.0 ± 3.16	2.60 ± 0.03	192.72
P-P-12	Eyelet-12	P/167x2/220Z	P/167	16.14	12.80	633.3 ± 0.63	2.90 ± 0.07	175.35
C-C-12	Eyelet-12	C/168x2/220Z	C/160	16.93	12.80	667.7 ± 1.85	2.67 ± 0.02	184.12
C-P-12	Eyelet-12	C/168x2/220Z	P/167	16.93	12.80	774.6 ± 4.22	2.93 ± 0.05	174.52
P-P	Pique	P/167x2/220Z	P/167	5.91	6.30	609.3 ± 0.40	2.83 ± 0.06	176.53
C-C	Pique	C/160x2/220Z	C/160	5.91	5.91	752.6 ± 14.25	3.07 ± 0.06	165.03
C-P	Pique	C/160x2/220Z	P/167	5.91	6.30	618.7 ± 1.67	2.70 ± 0	180.15

a) Face side of the laminated fabric; b) Back side of the laminated fabric

2.3 Methods

Initially, a pre-trial was conducted using laminated fabric samples constructed with eyelet-4 to determine the appropriate type of material that would meet automotive performance requirements, such as flammability, light fastness, abrasion resistance, burst strength, tensile strength and tear strength. The expected values for each of these properties must be met by the laminated fabrics to be used in automotive upholstery. The flammability test was carried out using the horizontal burning principle in the wale and course directions according to ASTM 635/FMVSS302. According to FIAT 7G.2000 1 requirements, the samples' flammability value in this test should be less than or equal to 100 mm/min. The light fastness test, with applied energy of 81.9 kj, was carried out using a grey scale according to FIAT 50451/01 to simulate the colour change of the laminated fabrics during their lifetime. The automotive laminated fabric should meet the FIAT 9.55441 light fastness requirement with a minimum scaling of 4/5. Automotive upholstery was subjected to two different abrasion test techniques, the Taber and Cesconi methods. The Taber test (ISO 5470/1:1999) simulates the most severe abrasion conditions for laminated fabrics. The samples were loaded with a weight of 1,000 g and subjected to 300 cycles with a stone disc during the measurements. The expected requirement of this test is that there should be no surface deterioration and no yarn breakage on the laminated fabric. On the other hand, in the Cesconi method according to FIAT 50455 and 50455/09, the abrasion material is the fabric that simulates passengers clothing. Using this method, the measurements were carried out for 3,000 and 6,000 cycles. The automotive laminated fabric should meet the FIAT 9.55441 requirement with a minimum scaling of 4/5 and 4 for 3,000 and 6,000 cycles, respectively. The bursting, tensile and tear strength values of the laminated fabrics were measured using a Zwick universal testing machine according to FIAT 50447, 50441/01 and 50442, respectively. The automotive upholstery should meet the FIAT 9.55441 requirement for bursting, tensile and tear strength values that should be equal or greater than 20 daN, 60 daN and 6 daN, respectively. While the results of mass per unit area, thickness, abrasion resistance (Taber and Cesconi method) and bursting strength are averages from the values of three readings, the flammability, tensile and tear strength values presented in Tables 3 and 4 are the mean value of five readings in course- and wale-wise. The type of material that could not meet the performance requirements for automotive upholstery was eliminated from the study based on the pre-trial results.

The laminated fabrics that passed the requirements tests were then measured for mass per unit area, thickness, air permeability, thermal conductivity and water vapour permeability. Mass per unit area values were measured according to TS EN 12127:1997. Fabric thickness and thermal conductivity values were tested using an Alambeta device according to ISO 8301. A Textest FX 3300 with a measuring area of 5 cm^2 and a pressure of 200 Pa was used for the determination of the air permeability properties of the samples. The results of air permeability presented in Table 5 are averages from the values of 10 readings. The water vapour permeability of the samples was tested using a Permetest device according to ISO 11092. The results of thermal conductivity and relative water vapour permeability are averages from the values of three readings.

Fabric density is the weight per unit volume of the fabric, which makes it possible to determine how strong, dense and permeable a fabric is. This parameter was therefore used to evaluate the thermal properties of the samples using equation 1 [26]:

$$\rho = \frac{M}{h} \tag{1}$$

where ρ represents fabric density (kg/m^3), M represents the fabric mass per unit area (kg/m^2) and h represents fabric thickness (m).

The requirements of automotive standards were considered when evaluating the results of the automotive performance tests. Multivariate analysis was used to evaluate the results of the mass per unit area, thickness and thermal properties. Differences were considered significant if the p-value for each dependent variable in Table 6 was equal to 0.05 or less.

3 Results and discussion

3.1 Pre-trial for the selection of the material type

Table 4 shows the results of the automotive performance tests carried out on the laminated eyelet-4 fabrics in the pre-trial. The results of the tests showed that 100% polyester and Type C laminated fabrics met all the performance requirements for upholstery fabrics, while all Type A and Type B laminated fabrics failed the Cesconi abrasion resistance tests. Based on these results, Type A and Type B laminated fabrics were excluded from the evaluation.

Table 4: Results of performance tests for eyelet-4 automotive upholstery laminated fabrics

Code of laminated fabrics	Flammability (mm/min) Coursewise/ walewise	Light fastness (81.9 kJ)	Abrasion resistance		
			Taber 300 cycles	Cesconi 3000 cycles	Cesconi 6000 cycles
	Requirement: ≤ 100	Requirement: ≥ 4/5	Requirement: OK	Requirement: ≥ 4/5	Requirement: ≥ 4
P-P-4	SE [a)]/96 [e)]	4/5	OK	4/5	4
A-A-4	85/86	4/5	OK	¾; Not OK	2/3; Not OK
B-B-4	91/88	4/5	OK	¾; Not OK	2/3; Not OK
C-C-4	86/82	4/5	OK	4/5	4

[a)] Self-extinguish

3.2 Automotive upholstery performance tests

Performance tests for automotive upholstery fabrics were carried out on laminated fabrics knitted from polyester and Type C yarns in three different structures, taking into account the results of the preliminary tests.

As evident from Table 5, all the laminated samples have a burning rate lower than 100 mm/min, a value of 4/5 for light fastness, an acceptable value from the Taber test, a value of 4/5 for Cesconi 3000 and a value of 4 for Cesconi 6000. In addition, their bursting strength is higher than 20 daN, their tensile strength is greater than 60 daN and tear strength exceeds 60 daN. Each sample exceeds the acceptable level of requirements, as shown by the performance test results. Consequently, the dimensional and thermal characteristics of all the laminated fabric samples were investigated in the next section.

Table 5: Results of performance tests for automotive upholstery laminated fabrics

Code of laminated fabrics	Flammability (mm/min) Coursewise/ walewise	Light fastness (81.9 kJ)	Abrasion resistance			Bursting force (daN)	Tensile force (daN) Coursewise Walewise	Tear force (daN) Coursewise Walewise
			a)	b)	c)			
	Requirement: ≤ 100	Requirement: ≥ 4/5	Requirement: OK	Requirement: ≥ 4/5	Requirement: ≥ 4	Requirement: ≥ 20	Requirement: ≥ 60	Requirement: ≥ 6
P-P-4	SE [d]/96	4/5	OK	4/5	4	91.04 ± 0.51	182.2 ± 6.52	34.0 ± 1.26
							239.8 ± 4.87	33.0 ± 2.53
C-C-4	86/82	4/5	OK	4/5	4	76.60 ± 0.51	148.8 ± 3.72	28.0 ± 0
							183.8 ± 8.23	25.0 ± 3.29
C-P-4	93/89	4/5	OK	4/5	4	89.42 ± 1.50	166.2 ± 4.71	28.8 ± 0.40
							183.8 ± 4.58	23.0 ± 2.28
P-P-12	85/95	4/5	OK	4/5	4	92.22 ± 2.11	170.6 ± 9.09	29.0 ± 0
							229.2 ± 4.45	32.8 ± 3.60
C-C-12	85/81	4/5	OK	4/5	4	73.82 ± 3.45	149.2 ± 5.15	29.0 ± 2.28
							178.2 ± 3.87	26.2 ± 2.64
C-P-12	89/86	4/5	OK	4/5	4	87.60 ± 4.30	162.0 ± 4.94	31.0 ± 1.26
							189.6 ± 10.33	27.2 ± 2.56
P-P	99/98	4/5	OK	4/5	4	64.56 ± 3.11	112.8 ± 5.78	26.8 ± 1.60
							247.8 ± 4.79	30.2 ± 1.33
C-C	98/100	4/5	OK	4/5	4	55.22 ± 1.55	101.8 ± 6.34	23.0 ± 0.63
							190.0 ± 14.95	25.8 ± 0.98
C-P	98/100	4/5	OK	4/5	4	69.28 ± 2.15	117.0 ± 1.41	25.8 ± 2.32
							228.0 ± 4.34	26.6 ± 0.80

[a] Taber 300 cycles; [b]; Cesconi 3000 cycles [c] Cesconi 6000 cycles; [d] Self-extinguish

3.3 Automotive upholstery thermal tests

Results of thermal comfort tests are given in Table 6. As evident from Table 3, the mass per unit area values of the laminated fabrics is in the range of 480–510 g/m^2. Although the C-P-12 fabric has the highest and the P-P-4 fabric has the lowest mass per unit area values, the statistical evaluation revealed that there are no significant differences between the mass per unit area values of the fabrics (Table 7). The thickness values of the laminated fabrics range from 2.60 to 3.70 mm. The highest and the lowest thickness values belong to the C-C and the C-P-4 laminated fabrics, respectively. Statistical analysis indicates that while the effect of yarn placement and fabric structure on thickness is significant, no general trend can be identified. Looking at the course densities of the laminated fabrics, the course density values of the eyelet fabrics are significantly higher than those of the pique fabrics, with little difference between them. The same is true for the wale densities.

Table 6: Results of the thermal tests of the laminated fabrics

Code of laminated fabric	Thermal conductivity ($Wm^{-1}K^{-1}$)	Thermal resistance (m^2KW^{-1})	Air permeability ($lm^{-2}s^{-1}$)	Water vapour permeability (%)
P-P-4	0.0426 ± 0.00	0.0672 ± 0.00	653.4 ± 19.70	23.00 ± 0.37
C-C-4	0.0441 ± 0.00	0.0619 ± 0.00	616.7 ± 35.26	24.20 ± 0.08
C-P-4	0.0440 ± 0.00	0.0592 ± 0.00	603.5 ± 33.38	27.43 ± 0.34
P-P-12	0.0427 ± 0.00	0.0679 ± 0.00	633.3 ± 50.55	26.30 ± 0.22
C-C-12	0.0441 ± 0.00	0.0604 ± 0.00	667.7 ± 27.09	28.27 ± 0.69
C-P-12	0.0438 ± 0.00	0.0667 ± 0.00	774.6 ± 23.46	24.60 ± 0.37
P-P	0.0430 ± 0.00	0.0656 ± 0.00	609.3 ± 34.22	23.90 ± 2.50
C-C	0.0425 ± 0.00	0.0720 ± 0.00	752.6 ± 27.84	25.70 ± 0.41
C-P	0.0427 ± 0.00	0.0636 ± 0.00	618.7 ± 13.32	24.07 ± 0.45

Table 7: Multivariate test results (for α = 0.05)

Parameter		F-value	p-value
Effect of yarn placement	Mass per unit area	0.927	0.414
	Thickness	4.480	0.026
	Thermal conductivity	3.246	0.063
	Air permeability	17.693	0.000
	Water vapour permeability	4.940	0.019
Effect of fabric structure type	Mass per unit area	1.256	0.309
	Thickness	21.880	0.000
	Thermal conductivity	3.620	0.048
	Air permeability	10.553	0.001
	Water vapour permeability	6.843	0.006
Effect of the interaction of yarn placement * type of fabric structure	Mass per unit area	3.900	0.019
	Thickness	12.880	0.000
	Thermal conductivity	2.206	0.109
	Air permeability	24.076	0.000
	Water vapour permeability	8.976	0.000

The total heat that passes through a fabric per unit of time for a unit change in temperature is represented by thermal conductivity (λ), which can be calculated using equation 2.

$$\lambda = \frac{Q}{t} \times \frac{T}{A \times \Delta T} \left({}^{W}/_{mK} \right) \quad (2)$$

where, Q represents the amount of heat; t represents time, T represents the fabric thickness; A represents the test area of the fabrics and ΔT represents the temperature difference.

Fabric density and thickness affect the ability of textiles to conduct heat. A higher fabric density means a lower amount of still air in the fabric structure and higher thermal conductivity. This is because the still air between the fibres has a lower thermal conductivity value than all other fibres (λ_{air} = 0.026) [27]. The body heat transferred through the seat, i.e.

the thermal conductivity of the fabric, is expected to be high, especially during long journeys [2].

The statistical evaluation (Table 7) shows that in terms of thermal conductivity values, the effect of material type is not significant, while the effect of fabric structure demonstrates a significant difference. It is evident that the laminated eyelet fabrics made of 100% Type C and Type C/Polyester (C-C-12, C-C-4, C-P-4, C-P-12) have the highest thermal conductivity values (Figure 1). In addition, the pique samples generally have lower thermal conductivity values. Since high thermal conductivity values are expected from automotive upholstery fabrics, it can be recommended to choose laminated eyelet fabrics with high thermal conductivity and low thickness values.

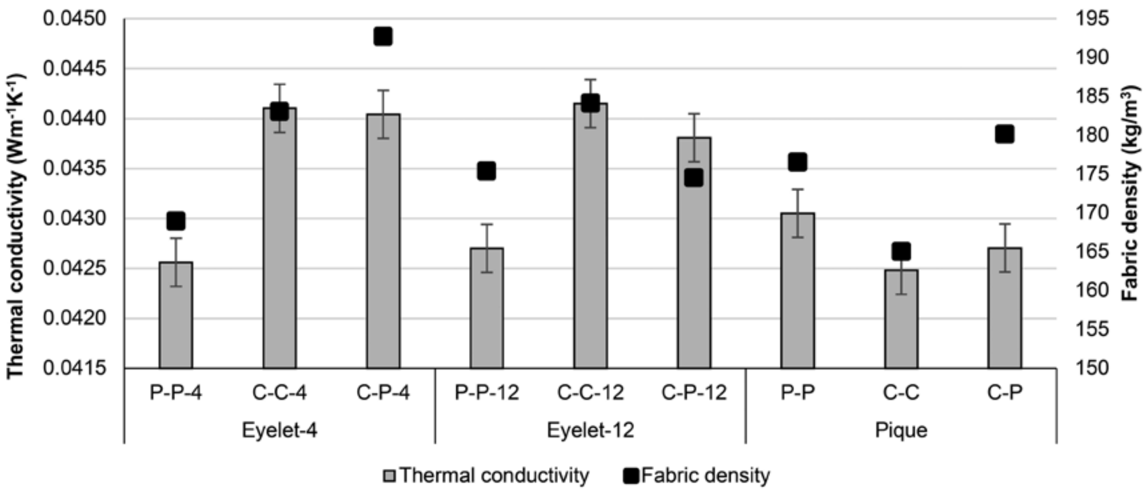


Figure 1: Thermal conductivity results

The air permeability of a fabric is one of the most important characteristics to evaluate and compare to determine its breathability. This value is the rate at which air moves through the fabric. Air permeability is mainly influenced by the fabric structure and bulk properties, in particular thickness, mass per unit area, fabric density and porosity. The higher the fabric density and thus the lower the porosity, the lower the air permeability of textile samples [28-29]. Similar to thermal conductivity, air permeability must be high in order to transfer heat and moisture produced by a passenger's body.

It was observed that fabric structure and yarn placement have significant effects on the air permeability values of the laminated fabrics (Table 6). The results show that C-P-12 and C-C laminated fabrics have the highest air permeability and the lowest fabric density values (Figure 2). This can be explained by the fabric density and type of fabric structures of these samples. The lower the fabric density, the higher the air permeability because air can more easily pass through the fabric. The highest air permeability values are found in the laminated eyelet-12 fabrics due to the highest mesh sizes within the investigated fabric structures illustrated in Table 2. In addition, using special yarns in the same fabric structure also increases air permeability.

Water vapour permeability indicates the rate at which water vapour can pass through a fabric under certain conditions. If a fabric is more permeable to water vapour, it is referred to as breathable [29, 30]. The porosity of textile materials and therefore their structure provides the basis for both air and water vapour permeability. However, both are affected differently. For example, while the pores between the yarns are considered important for air permeability, the material of the fibres is more important for water vapour permeability [31]. In order to maintain a dry

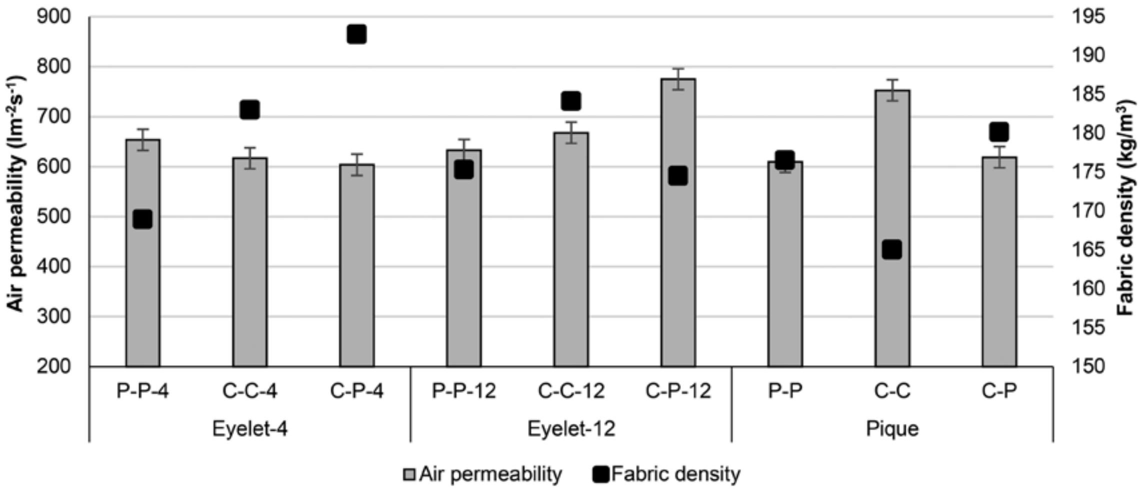


Figure 2: Air permeability results

microclimate between the driver and the seat, a car seat must have the highest possible water vapour permeability. According to the statistical evaluation, the differences between the water vapour permeability values of the laminated fabrics are significant (Table 7). However, the relative water vapour permeability values of the laminated fabrics are very close to each other, as seen in Figure 3. The results show that laminated fabrics containing Type C fibre, which has a channelled structure, have higher water vapour permeability. This can be explained by the inherent structure of the fibre. This yarn has channels that create a capillary effect and a larger surface area from which moisture can be quickly removed and as would be expected, water vapour permeability increases [25, 32]. As a result, laminated fabrics knitted with Type C yarn in an eyelet-12 structure, which has the highest water vapour permeability characteristic, can be recommended for automotive upholstery.

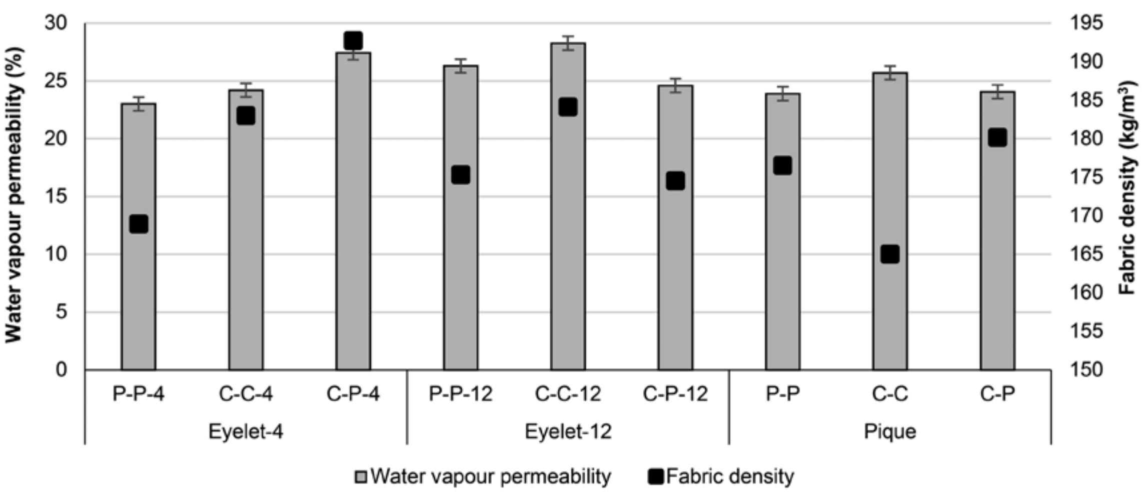


Figure 3: Relative water vapour permeability results

4 Conclusion

Pre-trials for the eyelet 4 structure showed that the test results belonging to laminated fabrics with 100% Type A and Type B yarns were below the acceptance limit in both 3000 and 6000 cycles in Cesconi abrasion resistance tests. Therefore, the study was performed using 100% polyester and Type C yarn that meet all the requirements of the automotive performance characteristics.

For the face fabrics, nine samples were produced with three different fabric structures (eyelet-4, eyelet-12 and Pique) and three different yarn combinations (Type C-Type C, Polyester-Polyester, Type C-Polyester). All samples met the requirements of the automotive upholstery performance tests.

The statistical evaluation shows that the effect of material type is not significant, but the effect of fabric structure demonstrates a significant difference between the samples' thermal conductivity values. Automotive upholstery fabrics are expected to have high thermal conductivity values, especially during long trips. Therefore, regardless of the material type, laminated eyelet fabrics with the highest thermal conductivity values are preferable. High air permeability is essential to transfer the heat and moisture produced by a passenger's body [33]. The results show that fabric structure and yarn placement have a significant effect on the air permeability values of the fabrics. The highest air permeability values belong to laminated eyelet-12 fabrics due to the lower fabric density. Due to the channelled characteristics of fibres, laminated fabrics produced with Type C yarn have higher water vapour permeability. Moreover, using special polyester yarn in the production of automotive upholstery fabrics improved the air permeability and water vapour permeability characteristics of the seat covers.

When all parameters are considered, laminated fabrics constructed using an eyelet-12 structure are lighter and thinner, and have higher thermal conductivity, air permeability and good relative water vapour permeability due to the porous surface structures and could therefore be recommended for car seats to improve comfort.

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Analysing E-Loyalty Dynamics in Fashion E-Commerce through Survey-Based Analysis

Analiza dinamike zvestobe v spletnih trgovinah z modnimi oblačili s pomočjo anket

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Abstract

This research paper delves into the intricate dynamics of e-loyalty in the context of fashion e-commerce. The study aims to scrutinise and evaluate the effectiveness of marketing strategies utilised by fashion e-commerce retailers, with a specific focus on cultivating customer loyalty in the digital realm. A robust survey methodology was implemented to collect and analyse data from a diverse sample of fashion e-commerce consumers. The survey method encompassed key aspects such as customer satisfaction, brand perception, online shopping experience and engagement with loyalty programmes. Through the application of advanced statistical techniques offered by SPSS, including bivariate analysis and factor correlation, the study seeks to unearth valuable insights into the factors influencing e-loyalty in the highly competitive landscape of online fashion retail. The findings are expected to contribute significantly to the existing body of knowledge in e-commerce marketing, providing actionable recommendations for fashion retailers to enhance their strategies and cultivate enduring customer relationships in the digital age. This combined survey-SPSS approach ensures a rigorous and data-driven exploration of the intricacies of e-loyalty, contributing to the advancement of understanding and practice in fashion e-commerce marketing strategies using SPSS. Moreover, survey methodology was implemented to collect and analyse data from a diverse sample of fashion e-commerce consumers to establish the correlation among various dependent and independent variables.
Keywords: e-loyalty, digital age, marketing strategies, consumer perceptions, SPSS

Izvleček

Članek obravnava kompleksno dinamiko zvestobe v spletnih trgovinah z modnimi oblačili. Namen študije je bil preučiti in oceniti učinkovitost marketinških strategij, ki jih uporabljajo trgovci v spletnih trgovinah z modnimi oblačili, še posebno spodbujanje zvestobe strank na digitalnem področju. Za zbiranje in analizo podatkov iz raznolikega vzorca potrošnikov v spletnih trgovinah z modnimi oblačili je bila uporabljena zanesljiva metodologija raziskovanja. Zajemala je ključne vidike, kot so zadovoljstvo strank, zaznavanje blagovne znamke, izkušnje pri spletnem nakupovanju in

sodelovanje v programih zvestobe. Z uporabo naprednih statističnih tehnik, ki jih ponuja SPSS, vključno z bivariatno analizo in faktorsko korelacijo, smo želeli pridobiti vpogled v dejavnike, ki vplivajo na zvestobo v izredno konkurenčnem okolju spletnih trgovin z modnimi oblačili. Ugotovitve raziskave naj bi pomembno prispevale k obstoječemu znanju o trženju v spletnih trgovinah in zagotovile uporabna priporočila za trgovce na drobno z modnimi oblačili za izboljšanje njihovih strategij in vzpostavljanja trajnih odnosov s strankami v digitalni dobi. Kombinirani pristop z raziskavo in SPSS zagotavlja dosledno in s podatki podprto raziskovanje kompleksnosti zvestobe ter prispeva k izboljšanju razumevanja in prakse na področju marketinških strategij modnega trgovanja z uporabo SPSS. Uporabljena je bila tudi metodologija ankete za zbiranje in analizo podatkov na raznolikem vzorcu potrošnikov v spletnih trgovinah z oblačili, da bi ugotovili korelacijo med različnimi odvisnimi in neodvisnimi spremenljivkami.
Ključne besede: zvestoba kupcev, digitalna doba, marketinške strategije, dojemanje potrošnikov, SPSS

1 Introduction

In the continually evolving landscape of e-commerce, the fashion industry stands as a dynamic sector where digital presence and customer loyalty play pivotal roles. As technology continues to reshape consumer behaviour, understanding and cultivating e-loyalty has become a strategic imperative for fashion e-commerce retailers. This research embarks on a comprehensive exploration of e-loyalty dynamics, focusing on the nuanced intersection of marketing strategies, consumer perceptions and digital engagement in the context of online fashion retail.

The emergence of e-commerce has transformed traditional retail paradigms, prompting fashion brands to navigate a complex online environment. E-loyalty, representing the commitment of customers to online platforms, has become a critical benchmark for success in this competitive landscape. To unravel the intricacies of e-loyalty, this study adopts a robust survey method, allowing for a nuanced examination of consumer preferences, satisfaction levels and interactions with various loyalty-building initiatives [1].

The Statistical Package for the Social Sciences (SPSS) serves as the analytical backbone, enabling a sophisticated exploration of survey data. By leveraging SPSS, this research aims to dissect the multifaceted components influencing e-loyalty, providing a deeper understanding of the factors that contribute to customer retention and satisfaction in online fashion retail. As the fashion industry navigates the challenges and opportunities presented by the digital era, this research seeks to contribute valuable insights to the field, offering actionable recommendations for fashion e-commerce retailers to refine their marketing strategies and fortify customer relationships in the ever-evolving digital marketplace. Figure 1 depicts fashion e-commerce users in India, categorised by age group.

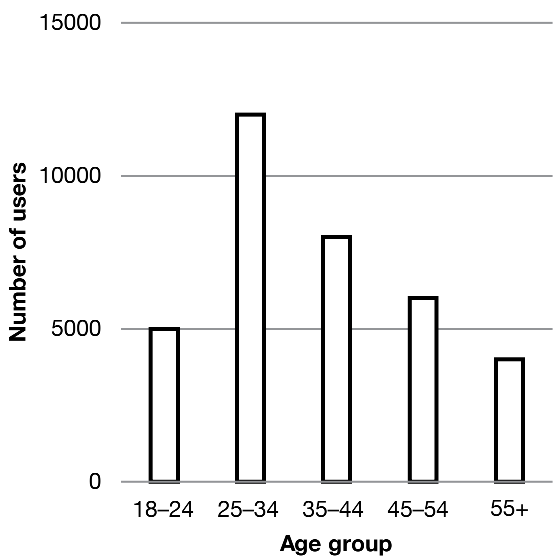

Figure 1: Fashion e-commerce users in India, categorised by age group till December 2023

1.1 Consumer perception of e-loyalty programmes

The digital revolution has not only reshaped the contours of retail but has also catalysed a metamorphosis in consumer expectations and engagement paradigms. E-loyalty programmes represent an innovative response to this shifting landscape, leveraging technology to transcend the limitations of traditional loyalty schemes. As businesses increasingly vie for the attention and loyalty of online consumers, understanding the intricate fabric of how individuals perceive and respond to e-loyalty programmes becomes imperative for organizations aiming to thrive in this competitive digital ecosystem. This research endeavours to dissect the layers of consumer perception surrounding e-loyalty programmes, investigating the factors that influence their effectiveness, the challenges that may hinder their adoption and the evolving strategies that businesses employ to navigate the complex landscape of online customer retention. By delving into the intricate interplay between consumers and e-loyalty programmes, this study aspires to offer valuable insights that can inform businesses in tailoring these programmes to meet the ever-evolving needs and expectations of their online clientele [2]. Through a judicious synthesis of academic research, industry practices and consumer feedback, this research paper seeks to contribute to the growing body of knowledge that underpins the symbiotic relationship between e-loyalty programmes and the discerning modern consumer. As online retailers strive to distinguish themselves in a crowded marketplace, electronic loyalty programmes (e-loyalty programmes) have emerged as crucial mechanisms for fostering lasting connections with consumers. This research seeks to unravel the intricate web of consumer perceptions surrounding e-loyalty programmes in the context of fashion e-commerce, with a specific focus on uncovering the implications of these perceptions for online retailers. The exponential growth of e-commerce has revolutionised the way consumers engage with fashion brands, prompting businesses to explore innovative strategies to secure customer loyalty. E-loyalty programmes, designed to incentivise repeat purchases and sustained engagement, represent a strategic frontier in this endeavour. Yet, the success of these programmes hinges largely on how consumers perceive and respond to them.

This study positions itself at the intersection of consumer behaviour, marketing strategy and digital commerce, aiming to dissect the implications that consumer perceptions of e-loyalty programmes hold for the dynamic landscape of fashion e-commerce. By adopting a survey-based approach and utilising advanced analytical tools such as the Statistical Package for the Social Sciences (SPSS), we endeavour to glean actionable insights that can inform and shape the strategies employed by fashion e-commerce retailers.

The goal is to not only understand the current landscape of consumer perceptions but, critically, to delineate practical implications that can guide businesses in optimising their e-loyalty initiatives. By doing so, we aspire to contribute from this research regarding valuable knowledge to the broader discourse on effective e-commerce strategies, providing a roadmap for fashion retailers seeking to build enduring and mutually beneficial relationships with their online clientele [3].

1.2 Background study

1.2.1 Navigating landscape of e-loyalty in contemporary commerce

Researchers have recognised the pivotal role of fostering customer loyalty as a vital avenue for companies to uphold competitiveness, ensure profitability and foster long-term growth for survival. It is asserted that nurturing exceptional customer loyalty is not just one strategy among many for-profit augmentations; instead, it has evolved into a necessity for organisational sustenance [4].

In the realm of e-commerce, e-loyalty as the customer's positive disposition toward the e-retailer results in recurrent purchasing behaviour. Thus, e-loyalty revolves around the customer's interest and intention to engage in future transactions with the provider. Furthermore, e-loyalty extends to the customer's inclination to recommend the company to others and express positive sentiments. E-loyalty is defined as customer satisfaction as "the contentment of the customer with respect to his or her prior purchasing experience with a given electronic commerce firm" [5].

1.2.2 Exploring customer satisfaction in e-commerce landscape

Research has identified e-satisfaction as a pivotal catalyst for fostering e-loyalty within the online industry. This implies that when a customer experiences satisfaction with an online company, there is substantial likelihood that the consumer will develop loyalty towards that brand. Asserting that, satisfied customers demonstrate a higher propensity to engage in repeat purchases from e-commerce entities. Consequently, when customers find satisfaction in their online experiences, their inclination to switch to alternative platforms diminishes. Research is driven by the ease with which consumers can switch between different online shopping sites, making them susceptible to changing their preferred platforms. The study aims to explore the role of e-satisfaction in mediating the impact of e-service quality and e-WOM (electronic word-of-mouth) on e-loyalty among online marketplace customers in Denpasar [6].

Moreover, satisfied customers exhibit greater willingness to recommend the service to others and actively contribute to positive word-of-mouth marketing. Additionally, their satisfaction serves as a deterrent against exploring alternative options or transitioning to competitors.

1.2.3 Significance of trust in e-commerce relationships

Research has been conducted to explore the correlation between e-trust and e-loyalty within the domain of e-commerce. The establishment of trust holds paramount importance as it possesses the capability to foster and sustain enduring relationships with customers, ultimately cultivating loyalty. This emphasises that e-trust is a fundamental prerequisite for achieving customer loyalty and retention, particularly in the context of online transactions where there is a perceived higher risk of compromising personal information. The concept of e-WOM plays a crucial role in the online visibility of individuals and businesses. e-WOM refers to any positive or negative comments made by potential, current or past customers about a product or company, which are accessible to a wide audience on the Internet [7]. This underscores the critical notion that if customers lack trust in online platforms, their reluctance to make purchases is likely to prevail. Therefore, for a company to secure customer loyalty, the foundational step is to trust in its online transactions in still.

1.2.4 Consumer choices in commerce price and brand selection

It needs to be emphasised that e-businesses must operate within a competitive price range to establish and sustain customer loyalty. Customers often perceive online channels as offering generally lower prices compared to traditional sales channels. This expectation is rooted in the belief that online markets can achieve greater efficiency through reduced transaction costs and the elimination of intermediaries. Customers may possess distinctive needs that prompt them to seek unique features, e.g. high quality, which are often uncommon or absent in traditional offline markets asserting that enhancing product quality has a positive impact on consumer satisfaction. Online retailers that provide an extensive array of products and choices play a pivotal role in retaining customers and demonstrating success. Furthermore, research revealed that a broader merchandise variety and competitive pricing exert positive effects on customer satisfaction in the realm of online shopping. E-WOM influences customer e-loyalty in the context of online banking and the role of e-satisfaction as a mediator factor as well as brand selection [8].

1.3 Research framework and hypothesis

This study involves an analysis of prior research conducted in diverse contexts to formulate hypotheses regarding various factors and antecedents influencing e-loyalty. Notably, limited attention has been given to the online fashion industry in existing studies. Given the recognised significance of e-satisfaction and e-trust in the e-loyalty development process, which offers mutual benefits for both consumers and businesses in the e-commerce landscape, this research seeks to empirically test the relationships between these factors and e-loyalty.

In addition to contributing to the existing body of knowledge, this study aims to explore various functional dimensions specific to top fashion and popular websites in the online fashion industry. These dimensions are identified as potential influencers of e-satisfaction and e-trust, subsequently impacting e-loyalty. Drawing from these considerations puts forth hypotheses that guide the investigation into the relationships among price, website design, selection of brands, e- satisfaction, e-trust and e-loyalty in the context of fashion retailers within the online fashion sector. Table 1 shows the research hypotheses.

Table 1: Research hypotheses

H1	Hypothesis on customer satisfaction
H2	Hypothesis on perceived value and benefits
H3	Hypothesis on e-trust
H4	Hypothesis on the effect of e-loyalty on word-of-mouth
H5	Hypothesis on the mediating role of customer satisfaction
H6	Hypothesis on the moderating role of demographic factors

H1: Hypothesis on customer satisfaction

This hypothesis suggests that there is a positive relationship between customer satisfaction with their online shopping experience and their loyalty to the e-commerce platform. In fashion e-commerce, satisfied customers are more likely to return and make repeat purchases, showing greater e-loyalty.

H2: Hypothesis on perceived value and benefits

This hypothesis assumes that customers who find high value and benefits in loyalty programmes are more likely to be loyal to the online fashion retailer. Effective loyalty programmes that provide rewards and special offers help retain customers and encourage them to keep engaging with the platform.

H3: Hypothesis on e-trust

This hypothesis states that higher levels of trust in the online shopping site are positively linked to purchasing fashion items. Trust involves feeling that the site is secure, reliable and has good customer reviews, which makes customers more likely to buy.

H4: Hypothesis on the effect of e-loyalty on word-of-mouth

This hypothesis suggests that customers who are more loyal to the e-commerce platform are also more likely to speak positively about it. Loyal customers tend to recommend the site and leave good reviews, which helps attract new customers.

H5: Hypothesis on the mediating role of customer satisfaction

This hypothesis proposes that customer satisfaction mediates the relationship between website design, brand choices, trust, perceived value and loyalty. Positive experiences in these areas lead to higher satisfaction, which in turn leads to greater loyalty.

H6: Hypothesis on the moderating role of demographic factors

This hypothesis examines how demographic factors like age, gender and income influence the relationship between customer satisfaction, perceived value and loyalty. These factors affect how customers perceive satisfaction and value, which then impacts their loyalty to the fashion e-commerce site. Understanding these effects can help tailor marketing strategies to different customer groups.

2 Material and methods

Classification framework being based on purpose, process, logic and outcome, this research can be categorised as both exploratory and descriptive. The exploratory classification is particularly relevant as it facilitates deeper understanding of the problem at hand. The flexibility to adjust the study's direction based on emerging data and insights is crucial in exploratory research. This approach is apt for addressing novel issues with limited existing research, as is the case in the e-commerce domain within the fashion industry.

A descriptive research approach was adopted from the perspective that this type of research is closely linked to the systematic gathering of data. Descriptive research enables a detailed exploration of the phenomena under investigation and is instrumental in providing a comprehensive overview of the subject matter. The combination of exploratory and descriptive research methodologies was deemed appropriate for this study. The exploratory aspect allows for a nuanced exploration of under-researched areas within e-commerce in the fashion industry, while the descriptive component facilitates the systematic collection and analysis of relevant data to achieve the study's objectives [9].

As per the research process, this study falls under the category of quantitative research, employing methods of data collection through a survey to gather empirical data from individuals. Subsequently, statistical methods are utilised to analyse the data, allowing for the assessment of participants' perceptions and behaviours and the testing of the proposed hypotheses. The classification of research strategies includes experiments, surveys, case study, history and archival research. In this study, the survey strategy was chosen. Surveys are often associated with descriptive or exploratory research designs, which align with the objectives of this study.

The survey consisted of two segments, i.e. the initial section centred on demographic profiles, while the second delved into the determinants of e-loyalty. Within the latter section, respondents utilised a Likert scale to express their opinions, with a range from 1 indicating "strongly disagree" to 5 indicating "strongly agree." Before disseminating the questionnaire, these queries underwent coding to streamline data processing in SPSS. The survey was generated using Google forms and was made available in English.

The survey form targeted 154 participants. The gender distribution among the respondents was 71.4% females and 28.6% males, the majority being between 18 and 24 years old. The survey commenced on December 27, 2023 and concluded on January 8, 2024.

After the completion of the data collection phase, the acquired information was subjected to an analysis utilising SPSS (Statistical Package for the Social Sciences) version 22.0. Following this, a comprehensive examination of the data ensued. Alongside the analysis, a reliability and validity test were executed to evaluate the strength and accuracy of the findings. The conclusive step encompassed validating whether the hypotheses were supported by the data or not [10].

3 Results and discussion

This section will present and analyse the survey results. The initial segment focused on a descriptive analysis, followed by a second part dedicated to a reliability and validity test of the research. Finally, a hypothesis test was conducted to ascertain the support for formulated hypotheses. A total of 154 respondents took part in the investigation. An introductory screening question assessed whether participants engage in online shopping for fashion items. The respondents who indicated "rarely" constituted 5.8% as shown in Figure 2.

The total sample consisted of 44 men and 110 women. This accounts for 100% of the sample, with 28.6% being males and 71.4% females who responded to the questionnaire. The age distribution among respondents was as follows: 65.6% were between 18 and 24 years old, 16.2% were between 25 and 34 years old, 11% fell in the 35 to 44 years age group, 5.8% were between 45 and 54 years old, and 1.3% above 55 years or older as shown in Figure 3.

Regarding the frequency of online clothing shopping, most respondents reported doing monthly shopping (43.5%). The second most common

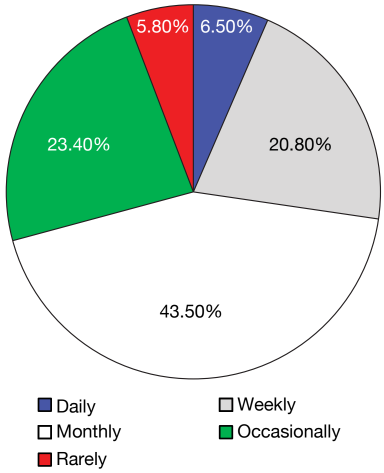

Figure 2: Respondents' participation in online fashion shopping

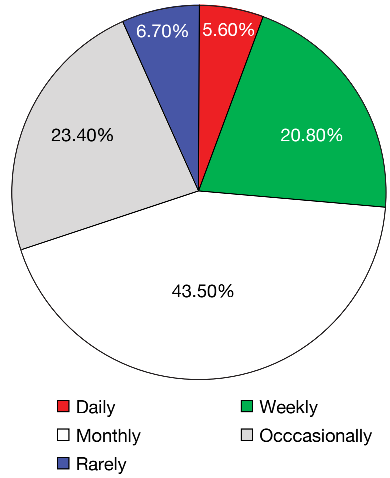

Figure 4: Frequency of online shopping

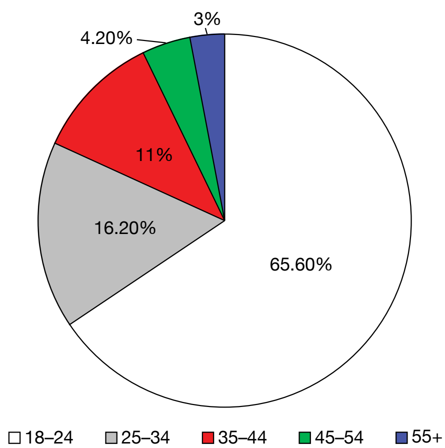

Figure 3: Age group distribution

frequency was "occasionally", accounting for 23.4% of the respondents. Additionally, 20.8% of the respondents mentioned shopping for clothing online approximately on a weekly basis as shown in Figure 4.

3.1 Practical implications

The next step involved conducting a validity test through the correlation analysis, which aimed to quantify the linear relationship between two or more variables. The chosen instrument for this analysis was the Pearson coefficient, a metric that gauges the strength and direction of the relationship. The coefficient can range from –1 (indicating a strong negative relationship between variables) to +1 (suggesting a strong positive relationship between variables). Moreover, when the correlation coefficient is close to zero, it implies that the variables are unrelated. This analysis was employed in the current study to assess the quality of the research and to determine the strength of the relationships between variables [11].

The results indicated a robust construct validity, as all variables exhibited a positive correlation with e-loyalty at a significant level of 0.01, signifying a high degree of confidence. Notably, the most substantial positive correlation was observed between e-loyalty and Brand communication with a coefficient value of 0.744.

The subsequent phase involved evaluating the support for formulated hypotheses through a multivariate linear regression analysis [12]. This analytical tool is employed to forecast the value of one or more responses based on a set of predictors, facilitating the estimation of the linear relationship between the predictors and responses [13]. In this context, the tool was utilised to examine the association of dependent variables with other variables as shown in Table 2.

A hypothesis is tested with each variable. The correlation is tested and plots are generated. There is a positive relationship between brand loyalty in fashion e-commerce with shopping experience and overall satisfaction as shown in Table 3.

Table 2: Model summary

Model	R [a)]	R^2 [b)]	Adjusted R^2	Std. error of the estimate
1	0.453	0.205	0.148	0.416

[a)] Multiple correlation coefficient; [b)] Coefficient of determination

ANOVA

Model 1	Sum of squares	Df [c)]	MS [d)]	F [e)]	Sig [f)]
Regression	6.203	10	0.620	3.587	< 0.001b
Residual	24.037	139	0.173		
Total	**30.240**	**149**			

[c)] Degrees of freedom; [d)] Mean square; [e)] F-statistic, [f)] F-significance level (p-value)

Table 3: Correlations between brand loyalty, shopping experience and overall satisfaction

Variable	Pearson correlation	Sig. (2-tailed)	N [a)]
Brand loyalty : Shopping experience	–0.089	0.271	154
Brand loyalty : Overall satisfaction	0.032	0.696	154
Shopping experience : Overall satisfaction	0.146	0.07	154

[a)] Number of participants

In the domain of online fashion retail, our hypothesis posits that the perceived value and benefits derived from participation in e-loyalty programmes play a pivotal role in nurturing customer loyalty [14]. Specifically, it suggests that customers perceiving elevated value and accruing substantial benefits from these loyalty initiatives are more inclined to exhibit heightened loyalty towards the online fashion retailer. Our primary objective, achieved through the correlation analysis, is to quantitatively measure the extent of the association between the perceived value, benefits and customer loyalty within the online fashion retail context [15]. A positive correlation coefficient would indicate that augmenting perceived value and benefits could strategically focus on fostering and reinforcing customer loyalty in the online fashion retail sector. This empirical investigation aims to yield valuable insights that can guide marketing strategies and the design of loyalty programmes within the ever-evolving landscape of online fashion commerce, as illustrated in Figure 5.

Figure 5: Brand loyalty and shopping experience

The ratings from customers are positively correlated with their preferred fashion categories, signifying that higher ratings coincide with a stronger preference for specific fashion categories [16]. This correlation implies a potential harmony between the perceived satisfaction and favoured fashion choices as shown in Table 4.

Table 4: Customer ratings and referred fashion categories

	Statistics	Customer ratings	Preferred fashion categories
Customer ratings	Pearson correlation	1	0.077
	Sig. (2-tailed)		0.343
	N	154	153
Preferred fashion categories	Pearson correlation	0.077	1
	Sig. (2-tailed)	0.343	
	N	153	153

4 Conclusion

This research delves into the intricate dynamics of e-loyalty within the context of fashion e- commerce, employing a comprehensive survey-based investigation supported by the Statistical Package for the Social Sciences (SPSS). The primary objective was to scrutinise and assess the effectiveness of marketing strategies utilised by fashion e-commerce retailers, specifically focusing on cultivating customer loyalty in the digital realm. Utilising SPSS, a robust survey methodology was implemented to collect and analyse data from a diverse sample of fashion e-commerce consumers. The survey encompassed crucial aspects such as customer satisfaction, brand perception, online shopping experience and engagement with loyalty programmes. Through the application of advanced statistical techniques, including bivariate analysis and factor correlation, the study aimed to unearth valuable insights into the factors influencing e-loyalty in the highly competitive landscape of online fashion retail. The anticipated findings were poised to make a significant contribution to the existing body of knowledge in e-commerce marketing, offering actionable recommendations for fashion retailers to enhance their strategies and cultivate enduring customer relationships in the digital age. This combined survey-SPSS approach ensures a rigorous and data-driven exploration of the intricacies of e-loyalty, contributing to the advancement of understanding and practice in fashion e-commerce marketing strategies.

Future scope and limitations

Future research in fashion e-commerce should explore the influence of emerging technologies such as AR, VR and AI on e-loyalty. Areas of interest include cross-cultural analysis, longitudinal studies and investigating personalised marketing and social media impact on e-loyalty. However, potential limitations should be acknowledged, including the risk of sample bias, temporal constraints, challenges in generalisation, reliance on self-reported data and external factors beyond the scope of the study. Addressing these concerns will contribute to a more nuanced understanding of e-loyalty dynamics in the evolving digital landscape of fashion retail, providing valuable, original insights for the industry.

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