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A study on the impact of digital transformation on innovation in textile and apparel companies: evidence from the Chinese market

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ABSTRACT – REZUMAT

A study on the impact of digital transformation on innovation in textile and apparel companies: evidence from the Chinese market

This study analyses data from 2010 to 2022 concerning companies listed on the Chinese A-share market to evaluate the extent of digital transformation within textile and apparel companies. Utilising the entropy method and the TOPSIS technique, the research assesses the impact of digital transformation on investment in innovation, including research and experimental development. Empirical findings indicate that digital transformation in these companies correlates with an increase in innovation investment. A more effectively marketised environment enhances the positive effects of digital transformation on innovation in traditional companies. Heterogeneous studies demonstrate that firms in Eastern China and high-tech companies exhibit more significant positive impacts from digital transformation on innovation.

Keywords: *textile, apparel, company, digital, innovation*

Studiu privind impactul transformării digitale asupra inovării în întreprinderile din sectorul de textile și de îmbrăcăminte: dovezi de pe piața din China

Acest studiu analizează datele din perioada 2010–2022 referitoare la societățile cotate pe piața chineză a acțiunilor de tip A pentru a evalua amploarea transformării digitale în cadrul întreprinderilor din sectorul de textile și de îmbrăcăminte. Utilizând metoda entropiei și tehnica TOPSIS, cercetarea evaluează impactul transformării digitale asupra investițiilor în inovare, inclusiv cercetarea și dezvoltarea experimentală. Constatările empirice indică faptul că transformarea digitală în aceste întreprinderi este corelată cu o creștere a investițiilor în inovare. Un mediu marketizat mai eficient sporește efectele pozitive ale transformării digitale asupra inovării în întreprinderile tradiționale. Studiile eterogene demonstrează că firmele din estul Chinei și companiile de înaltă tehnologie prezintă efecte pozitive semnificative ale transformării digitale asupra inovării.

Cuvinte-cheie: *textile, îmbrăcăminte, companie, digital, inovare*

INTRODUCTION

Innovation serves as a critical catalyst for national economic enhancement and reform. The "Three-Year Action Plan for the Digital Transformation of the Textile Industry (2022–2024)", issued by the China National Textile and Apparel Council in June 2022, underscores the imperative of amalgamating next-generation information technologies with the development of the textile industry. Prioritising intelligent manufacturing and focusing on the innovative applications of the industrial internet, the plan advocates for an accelerated digital transformation of the textile sector [1]. This study poses a critical inquiry: How does the extent of digital transformation within the textile and apparel industry affect organisational innovation? A significant challenge in this domain is the measurement of digital transformation. The prevalent method involves the use of survey data, as documented in existing literature; however, the subjective nature of this data may compromise the precision of the results. Additionally, the textile and apparel industry, being fully market-oriented with significant demand and low entry barriers, has proliferated across both economically advanced and less developed regions in China. This dispersion prompts another question: In the face of the twin challenges of digital transformation and corporate innovation, could regional disparities in marketisation influence the effect of digital transformation on textile and apparel firms, thereby either accelerating or impeding organisational innovation?

To address these questions, the current study analyses data spanning from 2010 to 2022 from textile and apparel companies listed on the Chinese A-share market. It evaluates the degree of digital transformation across two dimensions: business processes and technological applications. Furthermore, this research explores the relationship between organisational innovation and the extent of digital transformation, introducing a marketisation index as a moderating variable in this dynamic. The objective is to provide novel insights that enhance the innovation capacities of textile and apparel enterprises and to highlight the pivotal role of digital transformation within the industry.

LITERATURE REVIEW AND RESEARCH HYPOTHESES

Digital transformation in the textile and apparel industry and company innovation

The correlation between digital transformation and innovation has been predominantly viewed positively within scholarly discourse, with numerous studies analysing the influence of digital transformation on innovation from diverse perspectives. In examining the specific dynamics between digital transformation and innovation within the textile and apparel industry, the analysis can be segmented into two core areas: management processes and product development processes within these companies. At the management level, many textile and apparel firms traditionally adhere to hierarchical, conventional management structures and rely on manual business processes, often resulting in unnecessary and redundant steps [2]. Digital transformation facilitates a shift towards a more horizontal management architecture, which enhances inter-departmental oversight, reduces opportunistic behaviours among executives, and increases their accountability regarding performance-based compensation [3]. This transformation enables managers to exert more comprehensive control over business operations and to integrate internal resources more effectively, thereby optimising corporate performance. Ultimately, this contributes to enhanced competitiveness and supports innovative decision-making that is crucial for long-term development [4]. Digital transformation fosters new paradigms of thought and operational models in traditional settings. Therefore, textile and apparel companies are encouraged to augment their investments in digital technologies and infrastructures and expedite technological advancements. The digital transformation process notably improves the functionality and integration of companies' ERP and CRM systems, thereby enhancing their service orientation [5].

At the product development level, digital transformation impacts three primary stages. Firstly, during product planning, digital technologies enable more accurate forecasting of fashion trends through meticulous data analysis, overcoming the limitations of traditional apparel planning, such as lengthy development cycles, high subjectivity, disregard for consumer demands, and slow responsiveness to market shifts. Secondly, in the product design phase, digital technology has evolved from two-dimensional clothing pattern design and layout to advanced three-dimensional digital technologies, which include precise human body measurement, modelling, clothing design, cutting, sewing, and virtual clothing displays [6]. Finally, in the marketing phase, textile and apparel companies utilise digital technologies for both online and offline marketing strategies, targeted marketing on new media platforms, and the creation of immersive digital experiences [7].

Collectively, digital transformation in textile and apparel companies leads to a better understanding of consumer demands, reduces the probability of product rejection, decreases inventory levels, and enhances cash flow. Consequently, it is plausible to assert that digital transformation fosters research and development (R&D) as well as innovation within companies, thereby increasing their R&D investments. Based on these considerations, the study proposes the following hypothesis:

H1: Digital transformation in textile and apparel companies positively influences R&D intensity.

Company innovation, digital transformation, and marketisation

Drawing upon new institutional economics, the institutional environment is recognised as an external determinant of technological innovation within companies. In this context, the innovation capabilities of textile and apparel companies engaged in digitalisation are shaped and limited by both internal and external factors. Furthermore, the progress of digital technology is influenced by the level of marketisation. From a supply perspective, enhanced marketisation catalyses the steady progression of digital technology, creating a supportive environment for innovation and supplying the necessary elements for its fruition. From a demand perspective, higher marketisation levels lead to wider applications of digital technology, with shifts in consumer demand prompting the evolution of the digital technology-related industrial chain [8].

In terms of the digital transformation of textile and apparel companies, addressing various application scenarios within the industrial sector is crucial. This involves establishing connections with a wide array of personnel, equipment, and systems across the industry – a substantial effort that demands collective action from all stakeholders. When considering all influencing factors, the market emerges as the ultimate determinant. The higher the level of marketisation and the more robust the market mechanisms, the broader the provision of external business environment information to companies. Moreover, higher marketisation levels enhance the effectiveness of incentives and oversight for executives. Thus, the digital transformation of textile and apparel companies is intrinsically linked to market-oriented strategies. Based on these considerations, the study proposes the following hypothesis:

H2: The level of marketisation positively moderates the relationship between digital transformation and R&D intensity in textile and apparel companies. The conceptual research framework proposed in this study is depicted in figure 1.

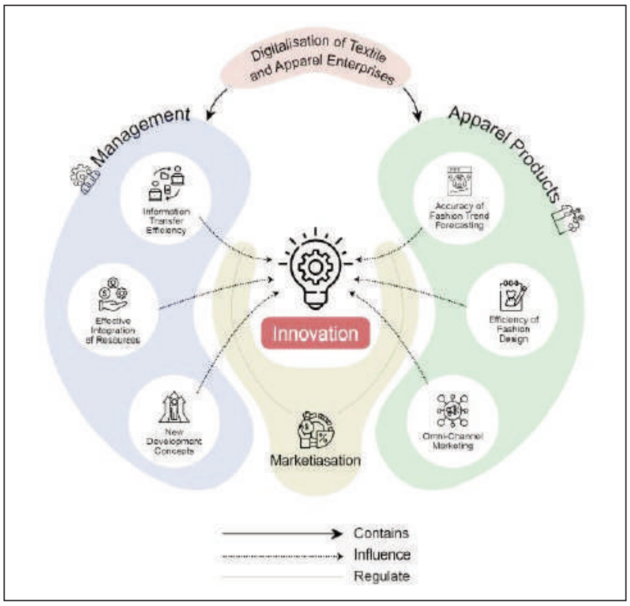

Fig. 1. Conceptual research framework

METHODOLOGY

Sample selection

This study focuses on textile and apparel companies listed on the China A-share stock exchange. To minimise the impact of missing data and errors, information is sourced from databases such as CSMAR and WIND, along with annual reports from Wallstcn.com. For instances of minor missing data for the same company across different years, the moving average method is employed to complete the dataset. To ensure a robust sample, the selection principle involves choosing data that covers an extended period. Given the digital development trajectory in the Chinese market, the selected sample period spans from 2010 to 2022. After excluding companies with abnormal financial conditions categorised under "PT" and "ST" designations, as well as those with missing data for key variables, the final research sample comprises 108 companies, amounting to 655 observations.

Variable description

Company innovation

In the extant literature, company innovation is frequently assessed using R&D intensity as a proxy for innovation input or patent counts to represent innovation output. Nevertheless, the use of patent data has its limitations as an indicator, since not all innovations result in patentable outputs, particularly in the context of Chinese textile and apparel companies, where a substantial proportion of imitative innovations may not yield patents [9]. While some studies incorporate both R&D expenditure and the number of R&D personnel to gauge innovation input, this approach can be problematic. Since R&D inputs include the salaries of R&D personnel, and the level of individual contribution varies, the salaries may serve as a more precise quantitative measure of innovation contributions. Therefore, this study posits that R&D inputs might represent a more accurate indicator of innovation input for textile and apparel companies. Furthermore, this study operationalises company innovation using R&D intensity (rd), defined as the ratio of R&D investment to total assets.

Digital transformation degree

This study employs the Entropy-Weighted TOPSIS method to measure the degree of digital transformation. The entropy weighting method is an objective approach that minimises the subjectivity in the weighting of evaluation indicators and facilitates an intuitive understanding of the efficacy of the information these indicators convey, aligning closely with practical requirements [10]. The TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method evaluates a limited number of entities by ranking them based on their proximity to an ideal solution, offering a comparative assessment of their relative merits and demerits. The integration of these methods in the Entropy-Weighted TOPSIS approach is particularly suited for complex, multi-criteria decision-making scenarios, providing benefits such as high evaluative efficiency, scientific rigour, and practical applicability [11]. The adoption of the Entropy-Weighted TOPSIS method thus ensures a more objective and reasonable quantification of digital transformation in enterprises.

The degree of digital transformation is abbreviated as "digi". Literature indicates that evaluating digital transformation should encompass four dimensions: strategic management, organisational culture, technology application, and business processes [12]. Challenges arise in gathering pertinent data concerning digital strategy at the level of strategic management, organisational structure within the cultural framework, and employee capabilities. Owing to these data constraints, the selected indicators for this dimension are the number of technical personnel and the efficiency of resource allocation [13]. The business process dimension comprises digital supply chain management, performance evaluation, and digital goods and services [14]. The evaluation system for assessing the degree of digital transformation in companies is detailed in table 1.

The entropy method determines the weight of each indicator, as illustrated in table 2. Following this, the TOPSIS method applies these weights to the normalised matrix, identifies the ideal positive and negative solutions, calculates the Euclidean distances, and computes the relative closeness to derive the evaluative score for digital transformation, which is then integrated into the model.

Control variables and moderating variables

Empirical research based on corporate financial data involves various variables. This study, drawing on key indicators from previous research on factors influencing corporate innovation and development, takes into account the unique characteristics of textile and apparel firms, such as significant differences in establishment periods and a stronger emphasis on market-driven factors [15]. Consequently, the study selects the following variables: company size (size),

Table 1

EVALUATION SYSTEM FOR THE DEGREE OF DIGITAL TRANSFORMATION			
Evaluation dimension		**Evaluation indicator**	**Indicator description**
Technology application level	Digital supply chain	Inventory optimization	The difference between the net inventory of the preceding year and the net inventory of the current year
	Performance evaluation	Cost control	Difference between the non-manufacturing costs of the preceding year and the non-manufacturing costs of the current year
Technology application level	Data-driven approaches	Number of Technical personnel	Total technical personnel at the end of the year
	Information system development	Resource allocation efficiency	Calculated using the DEA based on constant returns to scale

Table 2

WEIGHTS OF EVALUATION INDICATORS FOR DIGITAL TRANSFORMATION DEGREE				
Year	**Inventory optimisation (%)**	**Cost control (%)**	**Number of technical personnel (%)**	**Resource allocation efficiency (%)**
2010	3.42	4.87	56.73	34.98
2011	2.91	3.87	58.21	35.01
2012	3.26	5.28	54.81	36.65
2013	2.99	3.03	57.57	36.41
2014	3.48	4.18	50.34	42.00
2015	2.87	8.83	53.68	34.62
2016	5.13	3.22	57.16	34.49
2017	3.05	2.84	56.19	37.92
2018	4.51	3.74	57.16	34.59
2019	4.63	10.48	54.91	29.98
2020	5.02	7.52	55.34	32.12
2021	4.37	9.26	54.72	31.65
2022	4.83	8.71	58.16	28.30

return on assets (ROA), accounts receivable turnover ratio (REC), ownership proportion of the largest shareholder (Top), firm age (Firm Age), and the number of directors (Board). The marketisation index (market) functions as the moderating variable. This index quantifies the relative advancement of marketisation in Chinese provinces, autonomous regions, and municipalities directly under the central government. The foundational data for this index are derived from the National Bureau of Statistics, other relevant departments, and nationwide company surveys. This system comprises five dimensions, each represented by eighteen basic indicators, which include the relationship between the government and the market, the progression of the non-state economy, product market development, factor market development, the legal environment and the growth of market intermediary organisations. For the definitions and formulas of these variables, refer to table 3.

Model construction

Based on the fundamental method of model construction, this study incorporates all the aforementioned variables into the model to examine the impact of the degree of digital transformation on innovation in textile and apparel firms [16, 17]. The constructed model is as follows:

$$rd_{i,t} = \beta_1 Digi_{i,t} + \beta_2 Size_{i,t} + \beta_3 ROA_{i,t} + \beta_4 REC_{i,t} + \beta_5 Top_{i,t} + \beta_6 FirmAge_{i,t} + \beta_7 Board_{i,t} + \varepsilon_{i,t} \quad (1)$$

where i denotes the company; t is the year; $\varepsilon_{i,t}$ represents the error term, with Research and Development intensity (rd) as the dependent variable. The coefficient sign and magnitude of the term for digital transformation degree (digi) on the right side of the equation reflect the impact of digital transformation on R&D intensity and the investment in R&D personnel. Based on prior literature and hypotheses, we preliminarily speculate that this coefficient will be positive. To examine the moderating effect of the marketisation index (market), the following model is built, where X expresses the interaction term between digi and market after centralisation processing. Similarly, we preliminarily speculate that this coefficient will be positive:

$$rd_{i,t} = \beta_1 Market_{i,t} + \beta_2 Digi_{i,t} + \beta_3 X_{i,t} + \beta_4 Size_{i,t} + \beta_5 ROA_{i,t} + \beta_6 REC_{i,t} + \beta_7 Top_{i,t} + \beta_8 FirmAge_{i,t} + \beta_9 Board_{i,t} + \varepsilon_{i,t} \quad (2)$$

Table 3

VARIABLE DESCRIPTIONS AND CALCULATION FORMULAS			
Variable type	**Variable**	**Meaning**	**Variable description**
Dependent variable	Rd	R&D intensity	R&D expenditure / total assets
Independent variable	Digi	Digital transformation degree	Comprehensive evaluation value obtained through TOPSIS
Control variables	Size	Company size	Natural logarithm of total assets
	ROA	Return on assets	Net profit / average total assets
	REC	Accounts receivable turnover ratio	Ratio of net receivable to total assets
	Top	Ownership Proportion of the largest Shareholder	Proportion of shares held by the largest shareholder / total shares
	Firm age	Firm age	Number of years from the establishment of the company to the observation year
	Board	Number of directors	Natural logarithm of the number of directors
Moderating variable	Market	Marketization index	Obtained from the database of the marketisation index in each province of China

The study will make judgments based on the coefficients calculated. The sign of the coefficient corresponds to either a positive or negative correlation. The distinction between significance and non-significance is determined by the probability that the results are due to chance, represented by ***p, **p, and *p. For example, when $p < 0.05$, it indicates that the likelihood of obtaining an opposite conclusion in a repeated study under the same conditions is less than 5%. A p-value greater than 0.05 is considered "not significant," while $p \leq 0.05$ is considered "significant," and $p \leq 0.01$ is considered "highly significant." Additionally, after performing the regression analysis, the study uses the 'estat vif' test to ensure that there is no multicollinearity between the variables.

EMPIRICAL CONCLUSIONS AND ANALYSIS

Regression results on the relationship between digital transformation and company innovation

The baseline model's estimates are presented in table 4. The results indicate that the coefficient representing the impact of digital transformation on R&D intensity in textile and apparel companies is positive and statistically significant at the 5% level, thereby supporting Hypothesis 1. This hypothesis posits that an elevated degree of digital transformation in textile and apparel companies is associated with an increase in R&D intensity. A company's market position is influenced by various factors, including its revenue-based market share, company age, and size. Among the control variables, the coefficients for firm age and company size are both negative, aligning with the regression coefficient directions found in the study by Yue and Zhang [18], though with minor variations in significance levels. This negative association suggests that as companies mature, they might become complacent, diminishing their motivation for innovation and reform. In contrast, younger companies, often smaller and more dynamic, tend to exhibit a stronger drive for innovation [19]. Consequently, older and larger firms may inhibit innovative behaviours.

Concurrently, companies with a robust market position often display substantial revenue and sustained profitability. In such scenarios, the coefficient for ROA shows a significantly positive relationship with R&D

Table 4

IMPACT OF DIGITAL TRANSFORMATION ON COMPANY INNOVATION IN TEXTILE AND APPAREL COMPANIES	
Variables	**Rd**
Digi	0.0006**
	(2.2859)
Size	–0.0036***
	(–8.9230)
ROA	0.0370***
	(7.5697)
REC	0.0078
	(1.3339)
Top1	–0.0121***
	(–5.1914)
FirmAge	–0.0018
	(–1.5936)
Board	0.0104***
	(5.4684)
Constant	0.0707***
	(7.5734)
Observations	655
R-squared	0.2739
Indusry	Yes
Year	Yes

Note: t-statistics in parentheses; ***p<0.01, **p<0.05, *p<0.1.

intensity. Firms with healthy profit margins and stable profitability are more inclined to augment investments in innovation and R&D. The returns from such investments potentially enhance company revenue, thus creating a positive feedback loop. Additionally, there is a negative correlation observed between the ownership proportion of the largest shareholder and the number of directors. This suggests that in textile and apparel companies, a broad management team involved in decision-making is associated with greater investment in innovation and R&D. This finding aligns with the outcomes of a large-scale study encompassing various industries, underscoring a complex relationship between the market position of textile and apparel companies and digital transformation.

Moderating effect of marketisation level on the relationship between digital transformation in textile and apparel companies and innovation

Model 2 of this study investigates the moderating effect of the marketisation level on the relationship between digital transformation and R&D intensity in textile and apparel companies. The regression results, as shown in table 5, reveal that the coefficient for the interaction term is positive, albeit with a relatively low level of significance. This suggests that the impact of digital transformation on R&D intensity is enhanced as the marketisation level increases. This observation lends support to Hypothesis 2.

Table 5

THE MODERATING ROLE OF THE DEGREE OF MARKETISATION

Variables	Rd
Digi	–0.0028
	(–1.3870)
Market	–0.0006
	(–1.4873)
x	0.0003*
	(1.6702)
Size	–0.0035***
	(–8.6130)
ROA	0.0379***
	(7.6314)
REC	0.0081
	(1.3684)
Top1	–0.0119***
	(–5.0998)
FirmAge	–0.0016
	(–1.4002)
Board	0.0102***
	(5.3157)
Constant	0.0744***
	(7.6608)
Observations	655
R-squared	0.2775
Industry	Yes
Year	Yes

Heterogeneity analysis for further research

To enhance the precision of this study and deepen our understanding of the current developments within the textile and apparel industry, two additional factors were integrated into the research model: the geographic location of the company and its classification as a high-tech entity. The aim is to assess the differential impacts of digital transformation on innovation across these distinct structural dimensions.

The location of the company significantly influences its digital transformation trajectory. Companies in Eastern regions typically benefit from richer human and financial resources, more rapid technological advancements, and more profound reforms in traditional industries compared to their counterparts in non-Eastern parts of the country. Accordingly, this study categorises the sample into two groups: textile and apparel companies located in the Eastern region versus those in the non-Eastern region. A heterogeneity test is conducted within the empirical analysis to scrutinise these distinctions. In China, HNTEs exhibit a higher degree of digitisation compared to non-HNTEs. The sample is thus bifurcated into HNTEs and non-HNTEs, and a heterogeneity test is applied, with findings detailed in table 6.

The results indicate that the impact of digital transformation on innovation inputs is positively and significantly correlated at the 1% level for companies in Eastern regions. In contrast, for companies in non-Eastern regions, this impact is negative but not statistically significant. This discrepancy could be attributed to several factors: Firstly, textile and apparel companies in non-Eastern regions generally exhibit a lower quality of digital transformation and significant homogeneity, which undermines their competitive edge and diminishes their incentive to innovate. Secondly, companies in these regions are predominantly manufacturing-focused, with a dearth of original and innovative clothing brands, resulting in lower investments in innovation and R&D. Thirdly, there is a disparity in the focus on supportive policies for digital technology between the governments of Eastern and non-Eastern regions, with the former being more progressive and adept at implementing policies that promote corporate innovation and development. Both HNTEs and non-HNTEs show a positive coefficient regarding the impact of digital transformation on innovation intensity. This impact is statistically significant for HNTEs, suggesting that HNTEs have generally made notable strides in business model innovation through digital transformation and comprehensive informatisation management. In contrast, non-HNTEs face a significant degree of homogeneity in their digital transformation efforts, which have not yet been profoundly integrated into the core of their innovation processes.

Table 6

RESULTS FOR REGIONAL DIFFERENCES IN COMPANY LOCATION AND HI-TECH COMPANY CERTIFICATION				
Variables	**Eastern region**	**Non-eastern region**	**HNTE**	**Non-HNTE**
dig	0.0009***	–0.0008	0.0008**	0.0002
	(3.2120)	(–1.1614)	(2.5131)	(0.5125)
Size	–0.0039***	0.0001	–0.0022***	–0.0039***
	(–8.9314)	(0.0776)	(–3.4158)	(–7.3681)
ROA	0.0348***	0.0622***	0.0350***	0.0345***
	(6.6258)	(3.3751)	(5.3045)	(5.0151)
REC	0.0028	0.0552**	0.0349***	–0.0060
	(0.4519)	(2.3455)	(4.0859)	(–0.7493)
Top1	–0.0138***	–0.0126	–0.0058	–0.0107***
	(–5.6335)	(–1.1877)	(–1.3328)	(–3.7152)
FirmAge	–0.0022*	–0.0037	0.0011	–0.0057***
	(–1.7369)	(–0.9718)	(0.6764)	(–3.5213)
Board	0.0129***	–0.0088	0.0194***	0.0015
	(6.2357)	(–1.2947)	(7.9220)	(0.5384)
Constant	0.0735***	0.0350	0.0085	0.1083***
	(7.2335)	(1.1452)	(0.6309)	(8.4087)
Observations	575	80	280	375
R-squared	0.2963	0.4981	0.3930	0.2526

CONCLUSION AND DISCUSSION

This study explores the impact of digital transformation on innovation within textile and apparel companies, using data from 2010 to 2022 from firms listed on the Chinese A-share for empirical analysis. It further investigates the moderating role of marketisation in the relationship between digital transformation and company innovation. Key findings are as follows:

- Digital transformation has a positive impact on company innovation.
- Marketisation positively moderates the relationship between digital transformation and company innovation.
- Regression results for companies in eastern regions align with the empirical analysis, whereas those for non-eastern companies display contrary results in the main regression coefficients, although these are not statistically significant.
- Both HNTEs and non-HNTEs demonstrate a positive impact of digital transformation on innovation intensity, with the effect being significant for HNTEs but not for non-HNTEs.

These conclusions extend existing research on digital transformation in textile and apparel companies and the factors influencing company innovation. This study selects one indicator from each of four dimensions – digital supply chain, performance evaluation, data-driven approaches, and information system development – to comprehensively assess the degree of digital transformation in textile and apparel companies. This methodology addresses the limitations of previous literature that often relied on subjective and relatively narrow measurement techniques. Furthermore, the study clarifies the mechanism by which digital transformation in traditional companies influences innovation. Drawing on theories of marketisation, the research confirms a moderating effect within this dynamic. By differentiating between Chinese textile and apparel companies based on location and high-tech status, the study fills gaps in existing research.

The methodology employed can be summarised as the development of a digital transformation degree model, the construction of an empirical model, and the application of regression analysis. This approach provides a framework for companies to assess the effectiveness of their digital transformation initiatives. Additionally, the indicators or parameters can be tailored as needed to adapt the model for studies in other industries or regions.

China's textile and garment industry is currently at a critical stage of innovation-driven development. The transformation, upgrading of the industry, and the healthy, long-term development of the economy necessitate a continuous improvement in the innovation capacity of enterprises. As digital transformation represents the future trend of development, enhancing technological innovation capabilities is increasingly crucial for traditional textile and garment enterprises. Based on the findings of this study, the following specific recommendations are proposed:
1) Textile and apparel companies that have grown to a certain scale may experience a lack of innovation and flexibility in transformation. To address this, such companies could establish subsidiaries to externalize innovation units and focus on digital transformation

efforts; 2) Conversely, small-scale textile and apparel companies may need to invest substantial funds in the early and middle stages of digital transformation, potentially leading to reduced investment in R&D. These companies should seek more external financing and strategically allocate funds according to the different sources of financing; 3) Since geographic location significantly affects the digital transformation and innovation outcomes of textile and apparel companies, those with the necessary resources should consider relocating to regions with favourable government policies that attract investment, to capitalize on better development opportunities; 4) Becoming a high-tech enterprise is an effective path for textile and apparel companies seeking progress and development. Companies should continuously enhance their operations by aligning with the requirements of high-tech enterprises; 5) The business environment in which a company operates also influences its digital transformation. Local governments at all levels should enhance their support for industry-wide digital transformation by adopting targeted, multi-tiered support strategies and incentives. These measures should encourage social capital to participate in the integration of digital transformation and innovation within traditional enterprises.

However, this study faces certain unavoidable limitations. Firstly, the research is confined to companies listed on the Chinese A-share market, suggesting that future studies should extend the analysis to other entities across various regions. Secondly, the research uses marketisation as a moderating variable; however, there is a continuing need to investigate the effects of other factors on the digital transformation in the textile and apparel industry.

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Application research of a device with an anti-fall warning function on infant clothing

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ABSTRACT – REZUMAT

Application research of a device with an anti-fall warning function on infant clothing

The safety issues caused by falls during the growth process of infants and young children aged 0–3 have always been a concern. Currently, young parents need to take good care of their infants' and young children's daily lives while facing heavy work. While balancing life and work, anxiety is inevitable. This project mainly focuses on the safety of infants and young children and conducts online research on the feasibility of applying anti-fall warning devices to infant clothing. SPSS software is used to analyse the reliability, validity, and correlation of the collected data, and the necessity of using devices with anti-fall warning functions on infant clothing is concluded. We have developed and conducted relevant experimental data analysis on the function of anti-fall warning equipment. When the infant's body exceeds the set tilt angle, the warning equipment will emit a buzzing sound to remind the caregiver to understand the infant's activity status at first, reduce the risk of the infant falling, and alleviate the pressure on the caregiver. At the same time, the overall design of infant clothing, the design of anti-fall parts, and the placement of anti-fall warning devices on infant clothing were conceptualized, and corresponding finished products were produced. At the end of the project, an evaluation and assessment of the application of anti-fall warning devices in infant clothing was conducted to verify their market and functional feasibility, and to provide prospects for future research.

Keywords: *anti-fall warning equipment, evaluation and assessment, functional design, infant and toddler clothing, research and analysis*

Cercetări privind aplicarea unui dispozitiv cu funcție de avertizare anti-cădere pe îmbrăcămintea pentru sugari

Problemele de siguranță cauzate de căderi în timpul procesului de creștere a sugarilor și a copiilor cu vârste cuprinse între 0 și 3 ani au fost întotdeauna o preocupare. În prezent, tinerii părinți trebuie să aibă grijă de viața de zi cu zi a sugarilor și copiilor lor mici, în timp ce se confruntă cu o muncă grea. În timp ce echilibrează viața și munca, anxietatea este inevitabilă. Acest proiect se concentrează în principal pe siguranța sugarilor și a copiilor mici și efectuează cercetări online cu privire la fezabilitatea aplicării dispozitivelor de avertizare anti-cădere pe îmbrăcămintea pentru sugari. Software-ul SPSS este utilizat pentru a analiza fiabilitatea, validitatea și corelația datelor colectate și se concluzionează necesitatea utilizării dispozitivelor cu funcții de avertizare anti-cădere pe îmbrăcămintea pentru sugari. Am dezvoltat și am efectuat o analiză relevantă a datelor experimentale privind funcția echipamentelor de avertizare anti-cădere. Atunci când corpul bebelușului depășește unghiul de înclinare stabilit, echipamentul de avertizare va emite un sunet de bâzâit pentru a atenționa asupra stării de activitate a bebelușului de la bun început, a reduce riscul de cădere a bebelușului și a ușura activitatea îngrijitorului. În același timp, au fost conceptualizate designul general al îmbrăcămintei pentru sugari, designul pieselor anti-cădere și amplasarea dispozitivelor de avertizare anti-cădere pe îmbrăcămintea pentru sugari și au fost fabricate produsele finite corespunzătoare. La sfârșitul proiectului, a fost efectuată o evaluare și o analiză a aplicării dispozitivelor de avertizare anti-cădere pe îmbrăcămintea pentru sugari, pentru a verifica fezabilitatea lor comercială și funcțională și pentru a furniza perspective pentru cercetări viitoare.

Cuvinte-cheie*: echipament de avertizare împotriva căderii, evaluare și analiză, design functional, îmbrăcăminte pentru sugari și copii mici, cercetare și analiză*

INTRODUCTION

With the development of society, contemporary young parents need to learn how to become qualified parents while facing work pressure. The environment in which infants and young children grow up is quickly changing, and compared to traditional family care, modern parenting care is more challenging [1, 2]. With the transformation of consumer consumption concepts and the updating and iteration of high-tech, intelligent clothing is gradually occupying a high proportion in the infant and toddler clothing market, showing a trend of more specialization, intelligence, and segmentation [3]. When parents choose clothing for their children, they no longer only consider the comfort, safety, style, and structure of the clothing, but also pay more attention to its functionality.

According to research reports, the mortality rate of accidental injuries among children in China is 3–11 times that of developed countries, and accidental injuries among infants and young children are on the rise. Among accidental injuries among infants and young children, falls/falls are the highest, and the safety issues of infants and young children have

Table 1

CAUSES OF ACCIDENTAL INJURIES IN CHILDREN (%)							
Age group	**Gender**	**Falling**	**Blunt force injury**	**Knife/sharp instrument injury**	**Other**	**Motor vehicle accident**	**Nonmotorized vehicle accident**
0–4	male	60.42	9.9	6.01	9.89	6.71	7.07
	female	56.34	11.27	7.75	10.56	4.93	9.15

attracted more attention [4]. According to Huang Zhaosheng's [5] "Analysis of Children's Injury Monitoring Results", the top three causes of accidental injuries in children aged 0–4 are falls/falls, blunt object injuries, and nonmotor vehicle injuries. Children in this age group exhibit low cognitive abilities, strong curiosity, poor motor coordination, and are susceptible to injuries such as falls, bumps, and ingestion of foreign objects. The proportion of accidental injuries is shown in table 1.

The combination of an anti-fall Warning device and infant clothing needs to achieve the following functions:

1. The anti-fall Warning device should have the function of setting the tilt angle. Observing the physical activity of infants and young children can help determine the tilt angle of the body when it is about to fall.
2. The anti-fall Warning device should have a call function. When the body tilt angle exceeds a certain value, an alarm sound will be emitted.
3. Infant and toddler clothing can demonstrate protective performance. When infants and young children accidentally fall, clothing can provide some protection for areas that are prone to impact.
4. The integration of Warning devices and infant clothing. The Warning device can be integrated with infant clothing, and it should be easy to disassemble and recycle.

MARKET RESEARCH AND ANALYSIS OF ANTI-FALL CLOTHING FOR INFANTS AND YOUNG CHILDREN

The survey mainly adopts online research methods to distribute questionnaires in the mother and baby product group and the mother group, mainly targeting groups who need safety protection issues such as fall protection for infants and young children or have purchasing experience in infant clothing and supplies, providing data support for innovative design of fall protection clothing for infants and young children.

Research methods

Using online survey methods, questionnaires were distributed to shopping malls, maternity and baby stores, online maternity and baby groups, etc., over two and a half months. A total of 310 data research samples were collected, of which 301 were valid samples, with an effective rate of 97%. Using the SPSS system to analyse 301 questionnaires, reliability analysis, factor analysis, and correlation analysis were conducted on the collected data to analyse the impact of structural rationality, fabric composition, safety protection functionality, and the combination of infant clothing and intelligent devices on the demand for anti-fall clothing for infants and young children.

Questionnaire analysis on the demand for anti-fall clothing for infants and young children

Questionnaire Reliability analysis test

This article conducted a reliability test on question numbers 12–15 in the questionnaire data sample, with a total of 16 items. Cronbach's alpha coefficient is the most commonly used reliability testing method in questionnaire surveys. The value of Cronbach's alpha coefficient is usually between 0 and 1. If the alpha coefficient is lower than 0.6, it is considered to have poor reliability; If it reaches 0.6~0.7, it indicates good reliability; When it is higher than 0.8, it indicates high reliability. If the CITI value is below 0.3, it may be considered to delete the item; If the value of the "alpha coefficient for deleted items" is significantly higher than the alpha coefficient, it may be considered to delete the item and reanalyse it.

According to the results in table 2, the total Cronbach's alpha coefficient of this questionnaire is 0.923, which is higher than 0.8, and the coefficient values of the questions are all greater than 0.8, indicating that the various analysis categories of this questionnaire have high authenticity and accuracy, and the reliability quality is very high. Regarding the "CTIT" value, the CTIT values of the analysis items are all greater than 0.4, indicating a good correlation between the analysis items and a good level of reliability. The reliability coefficient of the research data is higher than 0.9, which comprehensively indicates that the data has high reliability quality and can be further analysed.

Questionnaire, Factor analysis, and validity testing

Questionnaire factor analysis aims to ultimately reduce its numerous variables into several factors, to verify the rationality of the selected data in the questionnaire. Commonly used test indicators are KMO value and Bartlett's sphericity value. If the KMO value is higher than 0.8, it indicates that the research data is very suitable for extracting information, that is, it reflects good validity from a lateral perspective; If the KMO value is between 0.7 and 0.8, it indicates that the research data is suitable for extracting information; A value less than 0.6 indicates that the data is not suitable for extracting information and has average validity. Validity analysis requires Bartlett's test (corresponding p-value should be less than 0.05).

Table 2

RELIABILITY ANALYSIS			
Name	**Total correlation of correction items (CITC)**	**The deleted α coefficient**	**Cronbach's α coefficient**
Problem 12-1	0.542	0.921	0.923
Problem 12-2	0.677	0.918	
Problem 12-3	0.583	0.920	
Problem 12-4	0.543	0.921	
Problem 13-1	0.663	0.918	
Problem 13-2	0.616	0.919	
Problem 13-3	0.583	0.920	
Problem 13-4	0.587	0.920	
Problem 14-1	0.651	0.918	
Problem 14-2	0.689	0.917	
Problem 14-3	0.574	0.920	
Problem 14-4	0.508	0.922	
Problem 15-1	0.473	0.922	
Problem 15-2	0.671	0.918	
Problem 15-3	0.554	0.920	
Problem 15-4	0.491	0.922	
Problem 16-1	0.701	0.917	
Problem 16-2	0.715	0.917	
Problem 16-3	0.588	0.920	
Problem 16-4	0.517	0.921	

Table 3

KMO AND BARTLETT'S TESTS			
Bartlett sphericity test	**KMO value**		**0.903**
		Approximate chi-square	1141.977
		df	36
		p-value	0.000

KMO and Bartlett were used to validate the validity of the anti-fall clothing requirements for infants and young children in questions 14–16. From table 3, it can be seen that the KMO value is 0.903, which is greater than 0.8 and meets the prerequisite requirements for factor analysis. At the same time, the data passed Bartlett's sphericity test ($p<0.05$), indicating that the research data is very suitable for factor analysis and reflects good validity indirectly. The questionnaire data meet the requirements of factor analysis and can proceed to the next step of analysis.

Correlation analysis

To verify whether there is a corresponding relationship between the performance and structural rationality of the fabrics in this questionnaire, the necessity of reflecting safety protection functions in infant clothing, and the necessity of using intelligent devices and the demand for anti-fall clothing for infants and young children, a correlation experiment was conducted on the questionnaire.

According to the experimental results in table 4, the correlation coefficients between the per infant clothing, and the necessity of using intelligent devices and the demand for anti-fall clothing for infants and young children are all 1, indicating that the variables in the questionnaire have a certain impact on formance and structural rationality of the fabric, the necessity of incorporating safety protection functions in consumers' purchasing needs.

Summary

This section conducted data analysis on the questionnaire through the SPSS system and provided explanations for the corresponding research results. According to the analysis, the validity, relevance, and credibility of the survey questionnaire are relatively high. At the same time, the performance and structural rationality of the fabrics in the questionnaire, the necessity of incorporating safety protection functions in infant clothing, and the use of intelligent devices can directly reflect consumers' demand for anti-fall functions in infant clothing. This survey provides a certain reference basis for the necessity of combining intelligent Warning devices with anti-fall clothing for infants and young children, and provides data support for subsequent designs.

Table 4

CORRELATION EXPERIMENT RESULTS							
Characteristic	**Indicator**	**Purchase demand**	**Performance of fabric**	**Rationality of structure**	**The necessity of demonstrating safety protection functions**	**Intelligent device usage**
Purchase demand	Correlation coefficient	1				
	P value	-				
Performance of fabric	Correlation coefficient	0.438**	1			
	P value	0.000	-			
Rationality of structure	Correlation coefficient	0.615**	0.566**	1		
	P value	0.000	0.000	-		
The necessity of demonstrating safety protection functions	Correlation coefficient	0.622**	0.459**	0.681**	1	
	P value	0.000	0.000	0.000	-	
Intelligent device usage	Correlation coefficient	0.275**	0.237**	0.208**	0.223**	1
	P value	0.000	0.000	0.000	0.000	-

Note: * $p<0.05$; ** $p<0.01$.

ANALYSIS OF ANTI-FALL WARNING DEVICES AND KEY POINTS IN THE DESIGN OF ANTI-FALL CLOTHING FOR INFANTS AND YOUNG CHILDREN

This section mainly focuses on the structural rationality design, fabric performance, functional protection, fall behaviour analysis, and application analysis of fall prevention Warning devices for infant clothing. During infancy and early childhood, it is easy to fall while crawling or just learning to stand. To relieve the pressure of guardianship, it is considered to combine the anti-fall Warning device with infant clothing, which is also the key to implementing the anti-fall Warning device in this project.

Analysis of the rationality of infant clothing structure

Infant and toddler clothing should be designed according to the characteristics of infants and toddlers. To avoid constraints, infant and toddler clothing needs to have sufficient relaxation, and there is no need to pay attention to the structure and style of the clothes. Instead, it is necessary to minimize stitching and avoid waist lines and weight loss; Infants and young children with short necks should preferably have no collar, and attention should be paid to the reasonable use of fastening structures.

Analysis of fabrics for infant and toddler clothing

Infants and young children have delicate skin that is prone to sweating. When choosing fabrics, attention should be paid to meeting the functional requirements of good breathability and moisture absorption, while also meeting the activity range of infants and young children [6]. Clothing fabrics for infants and young children should avoid fabrics with printing, dyeing, and finishing as much as possible to reduce the contact of harmful substances with infants and young children. When infants and young children learn to crawl, they sweat a lot and also need to go outdoors for activities. It is recommended to choose fabrics with good moisture absorption and breathability for their outerwear [7, 8]. Infants aged 10–12 months will gradually crawl and walk, and their range of activities will become wider. The preferred fabric is still sterile and pure cotton.

Functional protection

The most important thing in the growth process of infants and young children is to make fall protection performance a design focus. According to the literature review, currently, fall airbags are commonly used as materials for studying falls. Through AI intelligent calculation, when the speed and angle of a human fall reach a certain threshold, the clothing will automatically inflate the airbag protection material to protect important parts of the human body, such as the head and elbows [9, 10]. This fabric is relatively suitable for adults, but there are certain limitations for infants and young children, mainly because the operation requires a certain amount of gas, such as helium, to be contained in the material, which is not very suitable from a safety perspective. Due to the delicate skin of infants and young children, protective items such as sponge pads can be considered in the design to protect their elbow and knee joints.

Analysis of falling behaviour

The direction of human falls generally includes forward and backward falls and lateral falls [11]. When the human body is hit by a collision object, there is usually a reaction stage, during which the body will go through several stages of tilting, imbalance, and landing in sequence [12]. Taking a lateral fall as an example, the most obvious feature of the human body when about to fall is that the body tends to tilt. Generally, the line connecting the centre point S0 ‘of the two ankle support points and the centre point (S0) of the head when standing is taken as the centre line.

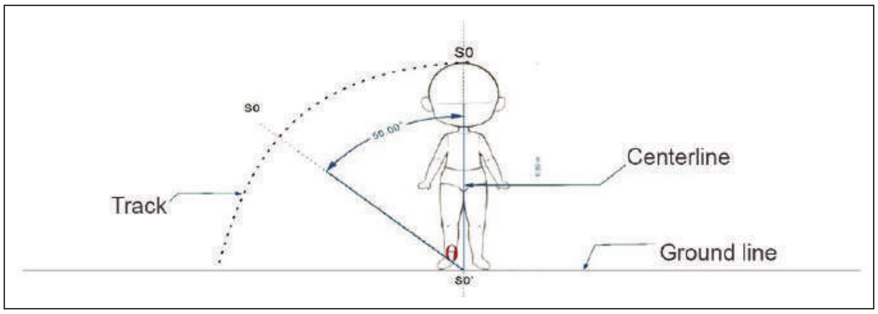

Fig. 1. Schematic diagram of the human body tilt trajectory

The angle (θ) between the centre line and the body tilt line is used as the standard for whether the human body is tilted. When θ reaches the set angle, it can be judged as a signal of imminent fall, as shown in figure 1.

Analysis of anti-fall warning device

The Warning device is developed based on the original IM948 series module, using Qt Creator integrated software combined with MSVC2019 compiler and C++ language. The developed page display is more specific and intuitive, and the main functions include Bluetooth connection, data display, 3D stereo, and dynamic curve.

Bluetooth function

By clicking on “Bluetooth Connection” to enter the Bluetooth page, click on “Search” to start searching for Bluetooth devices. If a gyroscope Bluetooth device is found, it will automatically connect and display the name and address of the gyroscope Bluetooth in the first blank area. The second blank area will display the progress and logs of the Bluetooth connection. Clicking ‘disconnect’ will disconnect from the Bluetooth of the connected gyroscope. If the Bluetooth connection is successful, the “Not Connected” label will become the name of the device connected to Bluetooth.

Data display

After receiving and parsing the data packet, the program will display the parsed data on the data page, such as angular velocity, magnetic field, etc. Whenever the state of the gyroscope changes (the content of the data packet changes), a data packet will be sent, and the program will parse it. At this time, the content of the data page will be refreshed.

The battery status is unique, and its information is not in the same data packet as other information. Here, a timer is used to send instructions to the gyroscope every five seconds to read the gyroscope’s battery level and charging status. When the gyroscope battery level drops below 5%, a battery alarm will be triggered.

Three-dimensional solid

Enter the 3D view page through “3D View”. Among them, x, y, and z respectively display the three values of the Euler angle of the gyroscope, and angle displays the angle between the gyroscope and the Z-axis (vertical direction). The middle is a cube made with OpenGL.

At the Bluetooth connection, the rotation axis coordinates and rotation angle of the gyroscope are calculated. Here, these two data points are passed as parameters to OpenGL’s rotation function to achieve the rotation of the cube graph, which is synchronized with the gyroscope’s motion.

Fig. 2. *3D Page*

Dynamic curve

This function adds angle lines and call lines based on the original module parameters. Based on this, the changes in human activity can be visually observed. The vertical axis of the curve represents the angle, and the horizontal axis has no meaning, only to better display the progress. The graph contains two curves; the black line is the threshold line, and the green line reflects the change in the angle between the gyroscope and the Z-axis.

When the program starts receiving data, start a timer and read the value of the angle every 50 ms, forming coordinates and connecting them into a curve in the table.

When the angle exceeds the threshold, the program will sound an alarm and send instructions to the gyroscope to raise one pin of the gyroscope, which is connected to a buzzer. When the angle exceeds the threshold, the program will sound an alarm, and the gyroscope buzzer will also sound an alarm. In addition, the angle curve will turn red, and the “unconnected” label on the Bluetooth interface will also turn red.

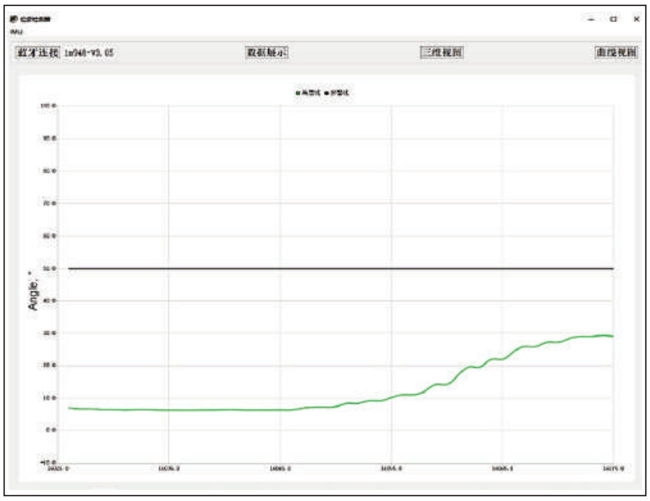

Fig. 3. Curve page when the angle does not exceed the threshold

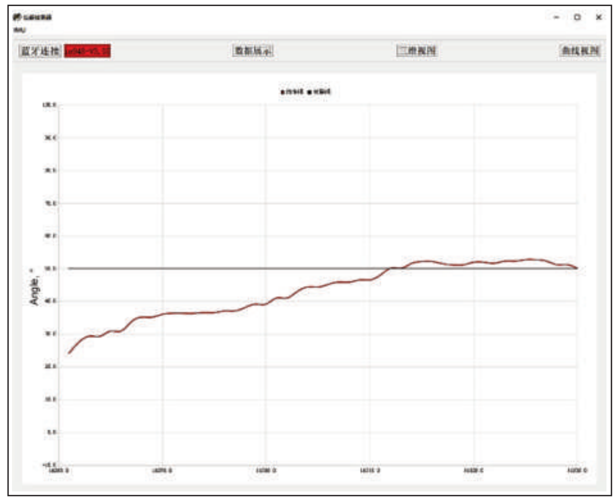

Fig. 4. Curve page when the angle exceeds the threshold

Program logic

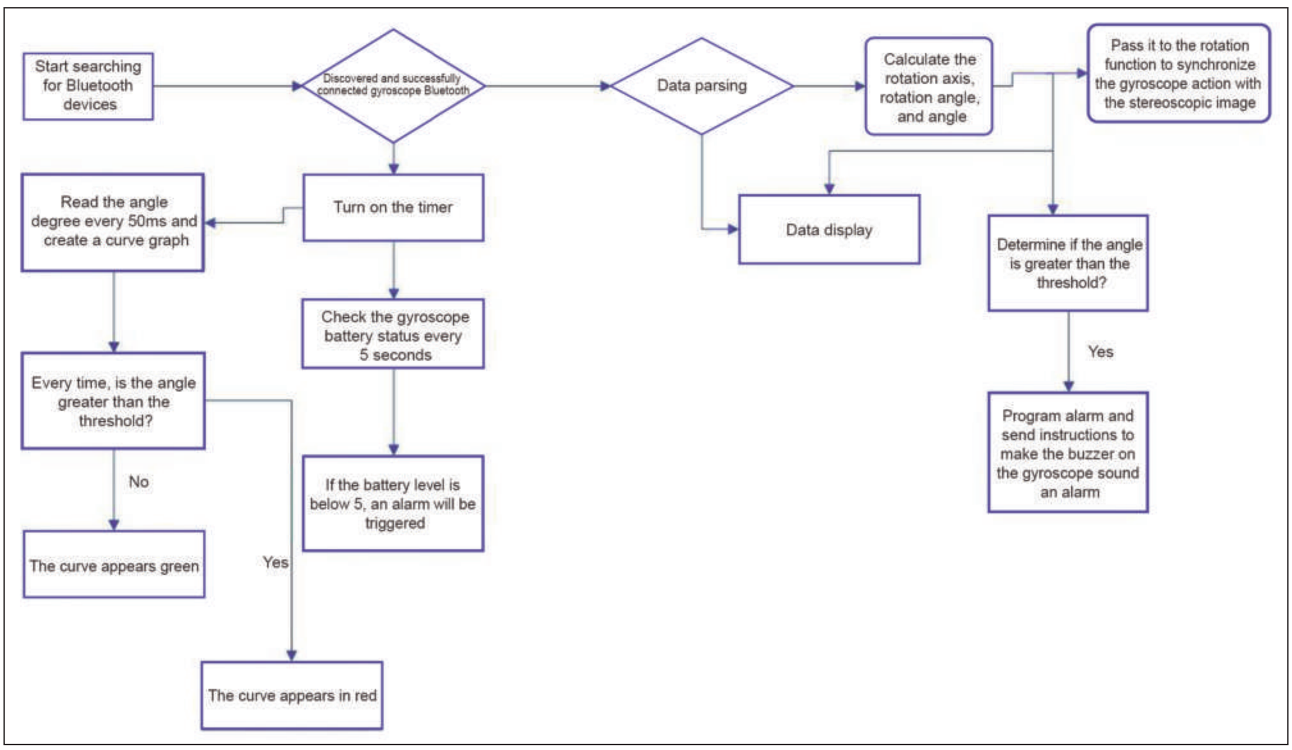

Fig. 5. *Flow chart*

Physical production and display of Warning devices

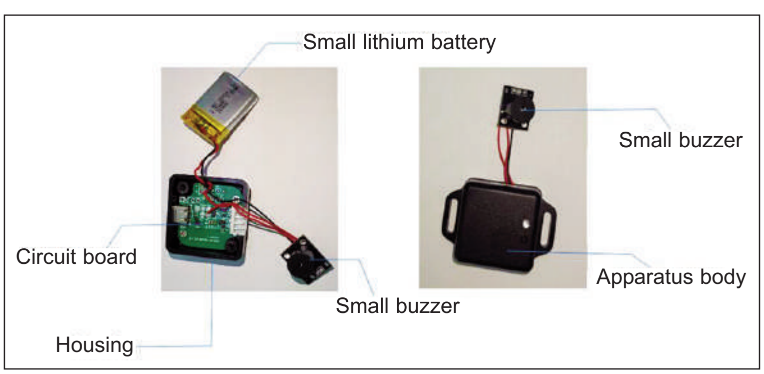

Fig. 6. Overall composition of the Warning device

Summary of this section

Infants and young children cannot take care of themselves, and to facilitate the care of guardians, the structural design of clothing needs to consider factors such as loose size and ease of wearing and taking off; During infancy and early childhood, the skin is delicate and prone to sweating, with weak resistance, and infants and young children are unable to express their body's discomfort to heat and cold. Therefore, when designing, the first step is to choose fabrics that have protective and safe properties for the skin of infants and young children. At the same time, sponge pads designed to prevent falls and impacts on joints such as elbows and knees can meet the needs of functional protection.

Secondly, the anti-fall Warning device is an important component in achieving the function of preventing falls in infants and young children. By detecting the physical activity status of infants and young children through the anti-fall Warning device, the possibility of falling can be determined. Allowing guardians of infants and young children to be informed of their child's condition promptly effectively avoids dangerous situations such as bumps and falls.

PRACTICE OF INFANT CLOTHING DESIGN BASED ON ANTI-FALL REQUIREMENTS

Based on the analysis of the design points of anti-fall clothing for infants and young children, two physical design schemes are proposed for the research topic, and one scheme is selected for physical production.

Design description

Taking childhood as the theme, searching for the innocence and carefree nature of childhood. In terms of design elements, starting from abstract letters, geometric elements such as straight lines are integrated into the design of clothing. The overall structure of the clothing adopts a jumpsuit style, which is convenient to put on and take off. In terms of style details, a round neck design is made, with straight access control; Sponge pads and other protective measures should be used at the joints to ensure the safety of infants and young children; The overall colour scheme is mainly blue and white, and the anti-fall Warning device weighs about 10 g. The device is lightweight and designed to be worn on the chest of clothing for easy disassembly by guardians.

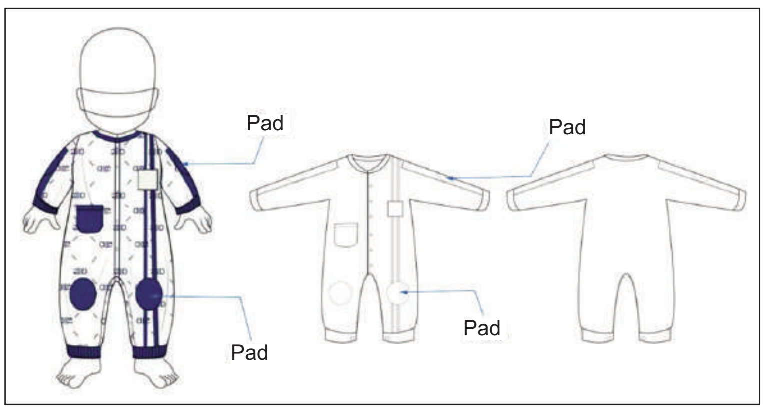

Fig. 7. Design proposal

Design renderings and style drawings, and detail production display

Application analysis

Evaluate and test the use of anti-fall warning devices on infant clothing, evaluate the appearance, functionality, and whether the use of anti-fall warning devices effectively alleviates guardian anxiety in the production of infant clothing, and analyze and summarize the results.

Evaluation of testing personnel

Five 1–2 year old infants and their guardians in the community were randomly selected as subjects for evaluation testing. The average weight of 5 infants

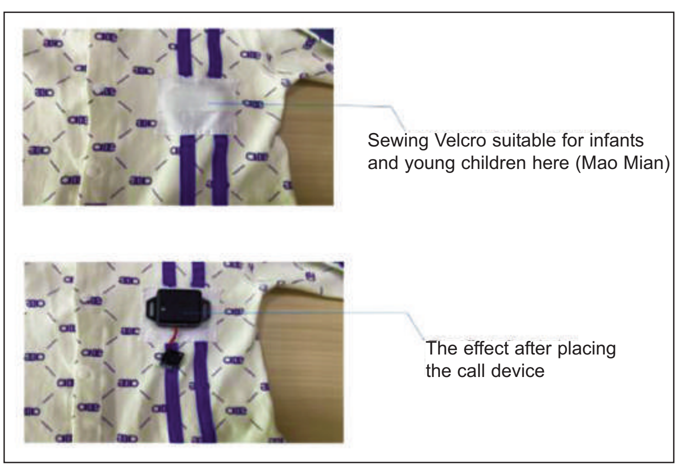

Fig. 8. Finished product detail display – combination of a warning device and clothing

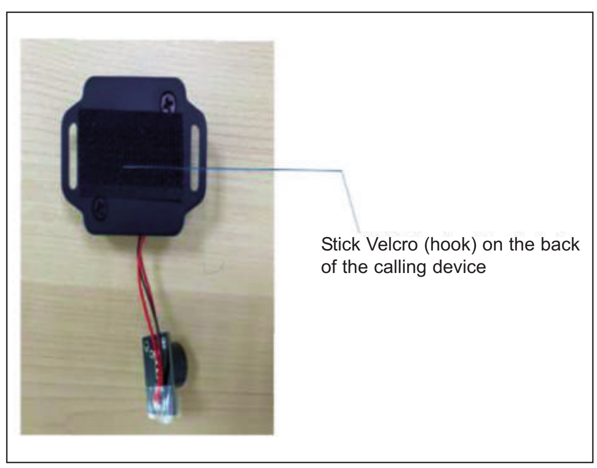

Fig. 9. Finished product detail display – Velcro (hook surface) pasted on the back of the Warning device

Table 5

SCORING RULES TABLE			
Evaluating indicator	**Evaluation content**	**Evaluation method**	**Evaluation level**
Appearance	Style aesthetics	Try on and observe	Very satisfied 3 satisfied 2 general satisfaction 1
	Comfort of wearing	Touch sensation	
Functional evaluation	Add protective design to the anti-fall parts	Feedback effect	Very satisfied 3 satisfied 2 general satisfaction 1
Evaluation of the combination of infant clothing and anti-fall warning equipment	The effect of combining anti-fall warning equipment with clothing	Relieve anxiety	Very anxious 3 Anxiety 2 General anxiety 1

and young children is between 10 kg and 12 kg, and their height is between 75 cm and 80 cm. The difference is small and can be used as a reference. Because infants and young children do not yet have good language expression abilities, guardians need to make evaluations on their behalf, and guardians also need to evaluate whether it effectively alleviates anxiety.

Evaluation testing using clothing

The infant clothing produced in this project is named Style "E" as the testing clothing. To better compare and verify with infant clothing on the market, we selected clothing styles with high praise rates for comparison. The infant clothing on the market is named Style "F".

Evaluation and testing methods

This evaluation mainly tests the appearance, functionality, and effectiveness of the baby clothing made, as well as whether it can effectively alleviate the anxiety of guardians when used in conjunction with anti-fall warning devices. Participants need to score based on their feelings, with high or low scores representing high or low satisfaction. The detailed rules for setting scores are shown in table 5.

Evaluation of Test Results

㈠ Appearance evaluation score

Table 6

APPEARANCE EVALUATION SCORE		
Subject	**Style E**	**Style F**
Subject 1	2.5	2
Subject 2	2.6	1.8
Subject 3	2.3	2.1
Subject 4	1.9	1.6
Subject 5	2.2	2.1

According to table 6, the evaluation scores of the five subjects for style E and wearing comfort are significantly higher than those for style F, indicating that the infant clothing produced in this study can win the Favor of consumers in terms of appearance design.

㈡ Functional evaluation score

Table 7

FUNCTIONAL EVALUATION SCORE		
Subject	**Style E**	**Style F**
Subject 1	2.3	2
Subject 2	2.1	1.5
Subject 3	2.6	1.8
Subject 4	2.4	2.2
Subject 5	2.8	2.1

According to table 7, the functional evaluation of style E by 5 subjects is higher than that of style F, indicating a high level of satisfaction with the functionality of the infant clothing designed in this study.

㈢ Effective evaluation score for alleviating anxiety

To effectively evaluate the level of anxiety of the guardians when the subjects were wearing and not wearing anti-fall warning devices, the experiment lasted for 2 days, and the records are as follows:

On the first day, 5 subjects did not wear clothing with fall warning devices, and the total number of falls recorded within 8 hours during the day was 25; On the second day, 5 participants wore clothing with fall warning devices, and the total number of falls recorded within 8 hours during the day was 18. When infants and young children are not wearing clothing with anti-fall warning devices, guardians need to take care of them without leaving within 8 hours. When infants and young children wear clothing with anti-fall warning devices, if their physical activity is about to fall, the anti-fall warning device will send a beep alarm reminder to the caregiver, and the guardian will pay attention to the infant's condition promptly. The guardian does not need to constantly monitor the infant's activity. A study on the level of anxiety among caregivers found that they were most anxious when they were not wearing fall warning devices; When infants and young children wear anti-fall warning devices, caregivers' anxiety is significantly lower, mainly due to the alarm reminder function of the anti-fall warning device, which relaxes the caregiver's mood. For this purpose, an evaluation score was also collected from the guardians regarding the alleviation of anxiety.

Table 8

EFFECTIVE EVALUATION SCORE FOR ALLEVIATING ANXIETY

Subject	Anxiety when wearing anti-fall warning devices	Anxiety when not wearing anti-fall warning equipment
Subject 1	1.1	2.3
Subject 2	1.5	1.8
Subject 3	1.2	2.2
Subject 4	1.3	2.6
Subject 5	1.2	1.9

According to table 8, when infants and young children were wearing clothing with anti-fall warning devices, the anxiety of the five guardian subjects was significantly lower than when infants and young children were not wearing clothing with anti-fall warning devices. This indicates that the application of the anti-fall warning device in infant and young children's clothing studied in this project is feasible.

CONCLUSIONS

Through literature review and analysis, the harmfulness of accidental falls in infants and young children was identified. Combined with the analysis of research questionnaires, the necessity of using devices with anti-fall warning functions on infant clothing in the market was concluded. Based on previous infant and toddler protective clothing research, research has been conducted on incorporating anti-fall warning equipment. The anti-fall warning equipment has been developed based on the original IM948 series module, using Qt Creator integrated software, MSVC2019 compiler, and C++ language for development. The developed page can be used more intuitively to see the activity status of infants and toddlers. The anti-fall warning equipment has the function of setting tilt angles and prompts, which has a certain application reference value for improving child safety and facilitating the care of young children. At the end of the project, an evaluation test was conducted on the use of anti-fall warning devices in infant and toddler clothing. The appearance, functionality, and effectiveness of the produced infant and toddler clothing in alleviating guardian anxiety were evaluated in three aspects. Based on the feedback provided by the evaluators, it was concluded that the infant and toddler clothing produced in this project can be loved by consumers in terms of appearance, design, and functionality. At the same time, when infants and young children were wearing clothing with anti-fall warning devices, the subjects' anxiety was significantly lower than when infants and young children were not wearing clothing with anti-fall warning devices. This indicates that the application of the anti-fall warning device studied in this project on infant and young children's clothing is feasible.

The significance of this research is mainly based on the safety of infant and young child growth, combining infant and young child clothing with anti-fall warning devices, and designing and considering the anti-fall performance of daily infant and young child clothing to minimize secondary injuries. Improve the injuries caused by accidental falls in infants and young children, and provide new ideas for the functional design of infant clothing. At the same time, it provides a certain reference value for the research on human body protection design of other functional clothing.

There are still some shortcomings in the research of this topic, and further supplements can be made in the following aspects:

1. Due to the constantly changing tilt posture of the human body, especially for infants and young children who are not yet independent in their daily lives, sometimes their movement posture may not necessarily be in a state of imminent fall. After the Warning device emits a prompt sound, it will increase the time for guardians to judge and recognize.
2. Currently, the project can only display the dynamic curve of the anti-fall Warning device on the computer. In the future, it is hoped that relevant technologies can be combined to achieve display on mobile apps or more convenient devices, making it easier to view data.

EXPECTATION

The research on fall prevention for infants and young children in this project is not yet very comprehensive. I look forward to the future development of infant and toddler protective clothing from the perspective of protective fabrics and related technologies.

1. The design of infant clothing needs to be combined with the growth characteristics of infants and young children. There are not many fabric materials available for use on infants and young children, and it is hoped that future research can develop a variety of protective fabrics suitable for infants and young children.
2. The use of intelligent products in the future will cover various fields, and infant protective clothing

is no exception. It involves interdisciplinary collaboration, and innovation and protective design alone are no longer sufficient to promote research on functional clothing for infant protection. I hope that in the future, more fields can pay attention to the infant and toddler population, providing them with a safe and reliable environment for their growth, while also reducing the caregiving pressure on guardians and enhancing their sense of happiness.

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The danger of wearing low-quality clothes. Part 1: Physicochemical characterisation

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ABSTRACT – REZUMAT

The danger of wearing low-quality clothes. Part 1: Physicochemical characterisation

Clothing has always played a vital role in people's lives, indicating social and moral status and the state of health. In a world where, for some, the appearance of a clothing product plays a much more important role than the quality of the product itself, it is necessary to know that although an item is fashionable and affordable, it may pose a real danger to health. Therefore, the main purpose of this article is to analyse, from a chemical point of view (phthalates and formaldehyde determination, FTIR measurements), the materials from which various clothing items are made and their behaviour under certain conditions (accelerated UV and visible light exposure), to highlight the danger of purchasing low-quality products. The obtained results showed that although the samples are inexpensive and look nice, they contain compounds dangerous for human health, such as phthalates and formaldehyde, which are present in materials that should not come into contact with skin and stained the material support after intensive light exposure.

Keywords: *clothes, phthalates, formaldehyde, FTIR measurements, UV exposure*

Pericolul purtării articolelor de îmbrăcăminte de calitate inferioară. Partea 1: Caracterizare fizico-chimică

Îmbrăcămintea a jucat întotdeauna un rol foarte important în viața oamenilor, fiind un indicator al statutului social și moral, precum și al stării de sănătate. Într-o lume în care pentru unii aspectul unui produs de îmbrăcăminte contează mai mult decât calitatea produsului în sine, este bine de știut că, deși un articol este la modă și la preț accesibil, poate reprezenta un real pericol pentru sănătate. Prin urmare, scopul acestui articol este de a analiza, din punct de vedere chimic (determinarea ftalaților și formaldehidei, măsurători FTIR), materialele din care sunt confecționate diverse articole vestimentare și comportamentul acestora în anumite condiții (expunere accelerată la UV si lumina vizibilă), cu scopul de a evidenția pericolul achiziționării de produse de calitate inferioară. Rezultatele obținute au arătat că, deși probele sunt ieftine și arată frumos, ele conțin compuși periculoși pentru sănătatea umană, precum ftalați și formaldehidă, care sunt prezenți în materiale care nu ar trebui să intre în contact cu pielea și să păteze suportul după expunerea prelungită la lumină.

Cuvinte-cheie*: îmbrăcăminte, ftalați, formaldehidă, măsurători FTIR, expunere la UV*

INTRODUCTION

Since ancient times, clothing has played an important role in the lives of humans, ensuring protection against environmental factors. Along with the evolution of society, there have been changes in clothing products, which are becoming increasingly complex, not only meeting protection requirements but also beautifying and acting as a form of expression. Price is often a deciding factor in the choice of clothes, but it must be taken into account that, most of the time, inexpensive clothing could pose health risks.

Textile materials can contain a wide variety of chemical compounds, depending on the type of fibres used, the manufacturing process and any finishing treatments applied [1]. Chemical finishes to textiles can greatly improve their wearability, appearance and functionality; can be durable or nondurable; and can bind different chemicals at different strengths to different fibres. To create a resistant finish and easy clothing care, chemicals are used to treat textiles, but they can generate dangerous compounds such as formaldehyde [2]. In dyeing processes, azo dyes or disperse dyes are used, but they generate aromatic amines, which have been proven to be carcinogens. Some of the chemical compounds used in textile materials can be harmful to human health or the environment [3–5]. For example, some dyes and finishes contain heavy metals or other toxic chemicals.

Phthalates have been shown to adversely affect human health, particularly in children [6–10]. Some phthalates can alter hormone levels in early life, potentially affecting reproductive health [8, 10]. A negative association between phthalate levels and thyroid hormone levels in children has also been demonstrated [11]. Epidemiologic studies have reported associations between phthalate exposure and obesity or cardiometabolic risk factors in children and adolescents [12, 13]. Accumulating evidence suggests that exposure to phthalates is negatively associated with lung function in children and with an increased risk of asthma and allergies [14].

Biometabolism in the human body is very rapid since phthalates have short biological half-lives of approximately 12 h. The first step of metabolism is hydrolysation after absorption into cells. The second step is conjugation to form a hydrophilic glucuronide conjugate, which is catalysed by the enzyme uridine 5′-diphosphoglucuronyl transferase [15]. The type of phthalate determines its toxicological fate in the body. Short-branched phthalates are often hydrolysed to monoester phthalates and then excreted in the urine, while long-branched phthalates mainly undergo several biotransformations, such as hydroxylation and oxidation, and are subsequently excreted in the urine and faeces as phase 2 conjugated compounds [16].

Studies have identified nonylphenol ethoxylate concentrations (NPEs), carcinogenic amines released from azo dyes within dyed fabric and phthalate esters in a broad range of textile clothing products [17]. A new group of chemicals, nonylphenol ethoxylates (NPEs), are used in the manufacture of textiles. The released NPEs can break down to form nonylphenols, which are bioaccumulative and toxic chemicals. The use of NPEs during the manufacture of cloth textiles can also leave residues within the final products.

Formaldehyde resins are usually used in the textile industry to prevent wrinkling. Exposure to formaldehyde can irritate the skin, throat, lungs, and eyes. The International Agency for Research on Cancer (IARC) classified formaldehyde as a human carcinogen [2]. Formaldehyde mediates its toxic effects by chemically modifying vital cell components, including DNA and proteins, thereby leading to cellular dysfunction. Formaldehyde-mediated genotoxicity is caused by the formation of DNA–DNA and DNA–protein cross-links, as well as covalent DNA monoadducts [18–21].

In recent years, there has been a very high interest in the ecological properties of textiles and chemical safety control of clothing articles to limit the negative effects of chemicals on human health. The toxicology of textiles is a subject of increasing interest because of the presence of dangerous compounds in clothes generated from dyeing and finishing processes.

This paper aimed to determine, through chemical analyses performed in a specialised laboratory and concrete results, the health risks of low-quality, inexpensive clothes for the first time.

EXPERIMENTAL SECTION

All chemicals and reagents were of HPLC or analytical grade and purchased from Sigma Aldrich. Ultrapure water used throughout the determinations was obtained from TKA GenPure.

Sample codification

The six samples (denim overalls for children, a blue dress for children, a white dress for children, trousers, a skirt, and a belt) were bought from the Obor Market (Bucharest, Romania) and were the least expensive in their category. The seller mentioned that the skirt and the trousers were made of "ecological leather".

The samples were codified as presented in table 1.

Table 1

SAMPLE CODIFICATION

No.	Sample	Codification
1	Jean overalls for children	J
2	Blue dress for children	D
3	White dress for children	W
4	Trousers	T
5	Skirt	S
6	Belt	B

The following tests were performed to characterise the samples.

Phthalate determination

All six samples were analysed according to standard EN ISO 14362-1:2017 "Textiles – Methods for determination of certain aromatic amines derived from azo colourants – Part 1: Detection of the use of certain azo colourants accessible with and without extracting the fibres" using GC equipment. Gas chromatography coupled with mass spectrometry (GC–MS 6890 N/5793 Agilent Technologies) was applied using a

Fig. 1. Images (from left to right) of sample jean overalls for children, blue dress for children, white dress for children, trousers, skirts, belt

DB-35MS capillary column (J&W®) 35 m in length with an inside diameter of 0.25 mm. Splitless injection was applied; the injector temperature was 250°C; the carrier gas was helium; the flow rate was 1 ml/min. The temperature program was as follows: 60°C (1 min) and heating at 20°C/min to 310°C (5 min). The injection volume was 1 µl, and detection was achieved with MS.

Formaldehyde determination

For the jean overalls and blue dress, and white dress for children, the formaldehyde content was determined by a spectrophotometric method according to the SR EN ISO 14184-1:2012 "Textiles – Determination of formaldehyde – Part 1: Free and hydrolysed formaldehyde (water extraction method)". UV-visible spectrophotometric determinations were performed with a Perkin Elmer UV-Visible spectrometer, with a maximum absorption peak of formaldehyde at 412 nm.
The formaldehyde content of the trousers, skirt and belt was determined according to EN ISO 17226-2: 2019 "Leather. Chemical determination of formaldehyde content – Method using colourimetric analysis" with a Jasco 550 UV-Visible spectrophotometer.

FT-IR measurements

FT-IR-ATR measurements were performed to determine the composition of the polymeric samples (trousers, skirt and belt) using 4200 Jasco equipment.

Colorimetric measurements

To simulate sunlight conditions, the samples were exposed to UV light using a VL 6LC UV lamp with irradiation at 365 nm and to visible light using a lamp with the following specifications: NXS-500P, 130 V AC 50 Hz7S, Adeleq.
Colourimetric measurements were made before and after UV and visible exposure, and a Data Colour DS-220 device and dedicated software were used.

RESULTS AND DISCUSSION

Phthalate determination

The results of the phthalate determination for children's clothing are presented in table 2.
Given that these are clothes for a vulnerable population (children), these compounds should not be found in the material components. In the skirt sample, dibutyl phthalate and iso-octyl phthalate were identified.
Exposure to high levels of dibutyl phthalate by inhalation can irritate the eyes, nose and throat. Exposure may also cause nausea, tearing of the eyes, vomiting, dizziness and headache. Long-term exposure may cause liver and kidney damage. Dibutyl phthalate may lead to male and female infertility and harm the development of fetuses. According to the classification and labelling (ATP15) approved by the European Union, di-iso-octyl phthalate may affect fertility and unborn children. The trouser sample contained bis(2-ethylhexyl) iso-phthalate.
This compound is considered a human carcinogen.
The belt contains dibutyl phthalate and di-iso-octyl phthalate.
A recent report described increases in the incidences of hypospadias ($p<0.05$), cryptorchidism ($p<0.05$) and breast cancer ($p<0.05$) in the children of New Zealand soldiers who served in Malaya (1948–1960)

Table 2

PHTHALATE IDENTIFICATION AND EFFECTS ON HEALTH		
Sample	**Substance**	**Effects on human health**
Jean overalls for children	2,4-di-tert-butyl-phenol (PRODOX 146), CAS 96-76-4	causes skin and upper respiratory tract irritation
Blue dress for children	2,4-di-tert-butyl-phenol (PRODOX 146), CAS 96-76-4	causes skin and upper respiratory tract irritation
White dress for children	di-iso-phthalate CAS: 27554-26-4	causes skin and upper respiratory tract irritation

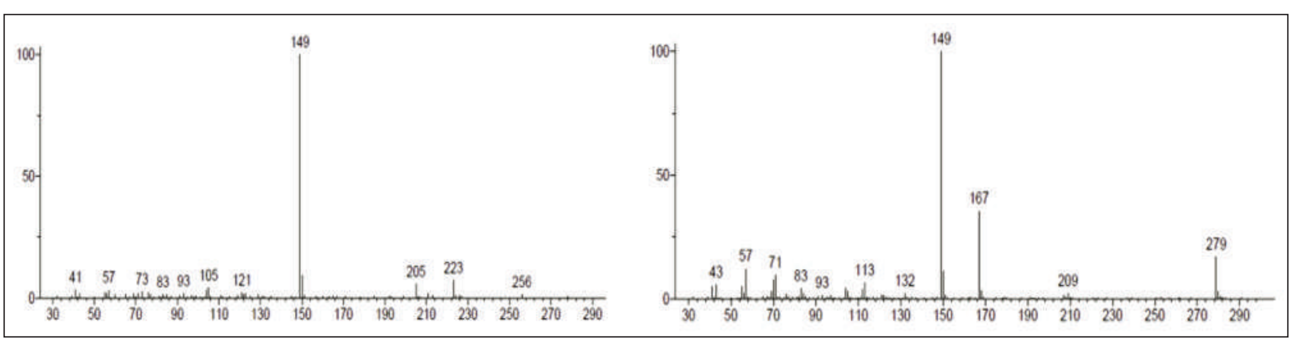

Fig. 2. MS spectra of dibutyl phthalate (left) and di-iso-octyl phthalate (right) detected in the skirt sample

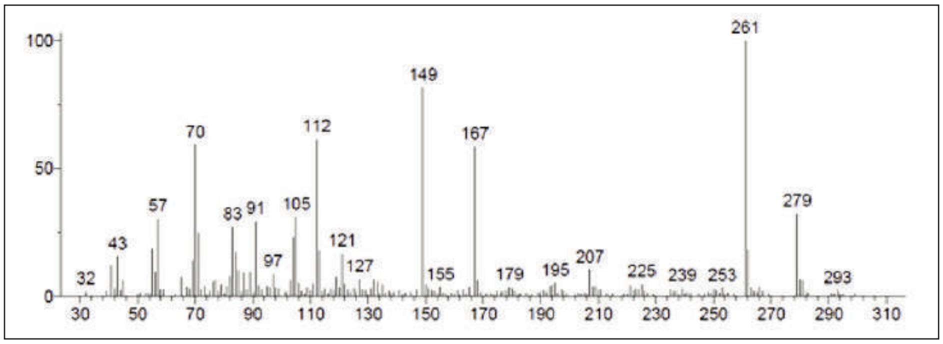

Fig. 3. MS spectrum of bis(2-ethylhexyl) iso-phthalate detected in the trouser sample

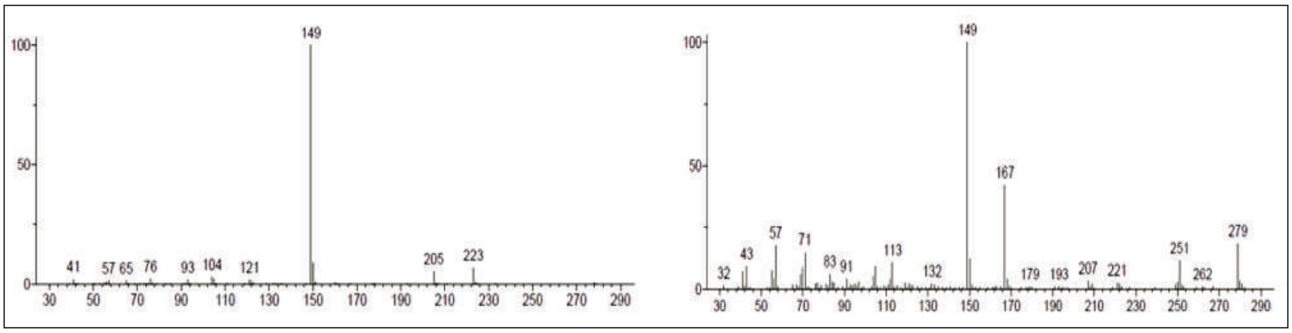

Fig. 4. MS spectra of dibutyl phthalate (left) and di-iso-octyl phthalate (right) in the belt sample

and were exposed to DBP applied daily to their clothing as an acaricide to prevent tick-transmitted bush typhus [22].

Formaldehyde determination

The results obtained for the quantitative determination of formaldehyde are presented in table 3.

The formaldehyde content obtained for the white dress sample was 5 times greater than the maximum allowed limit for the following category: textiles in no direct contact with the skin (150 mg/kg). This category was referred to because the dress also has a lining underneath. This value is extremely high for a product that is designated for children.

FT-IR measurements

FT-IR-ATR measurements can provide useful information about the composition of a sample. Here, this technique was used to reveal the chemical profile of the samples.

Figure 5 shows the spectrum of the belt material compared with a similar database spectrum.

Based on the information provided by the FT-IR database, regarding component identification, with an accuracy of 78.09%, the belt material was a Tygon polymer (specific for hose manufacture).

The FT-IR (ATR) spectrum of the skirt is presented in figure 6.

Table 3

FORMALDEHYDE CONTENT

Sample	Formaldehyde concentration (mg/kg)
Jean overalls for children	8.81
Blue dress for children	1.53
White dress for children	769.68
Trousers	64
Skirt	15
Belt	37

With an accuracy of 72.99%, the skirt sample material is a mixture of polyester and urethane. Both products are used in the clothing industry because they

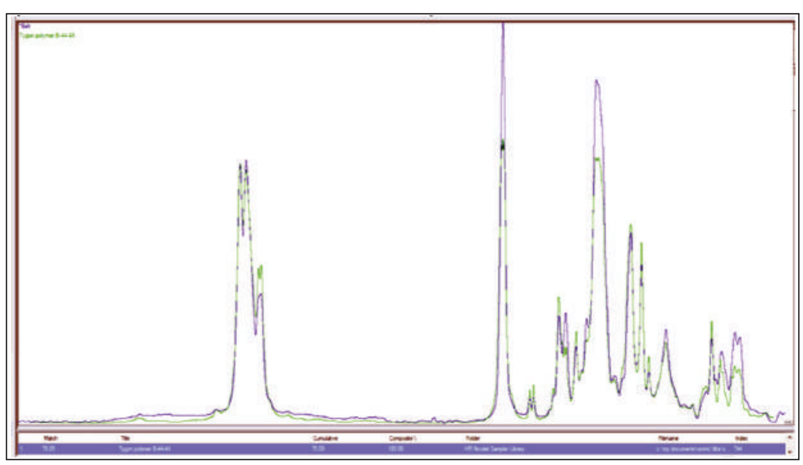

Fig. 5. FT-IR (ATR) spectra of the belt sample (blue) and the Tygon polymer (database)

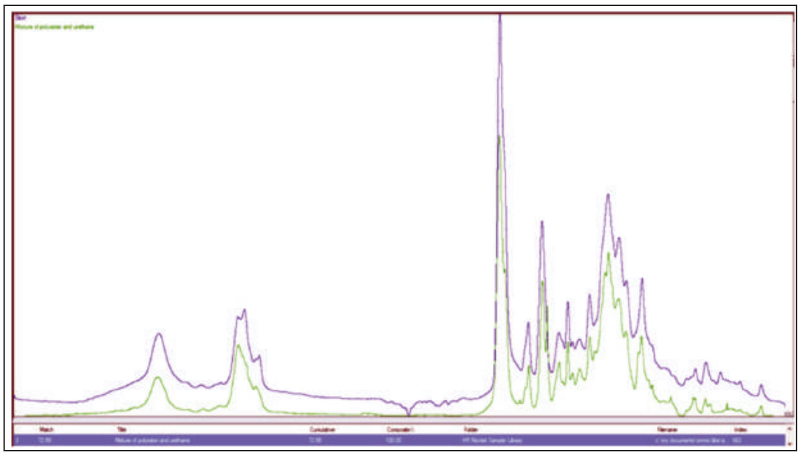

Fig. 6. FT-IR (ATR) spectra of the skirt (blue) and a mixture of polyester and urethane (database)

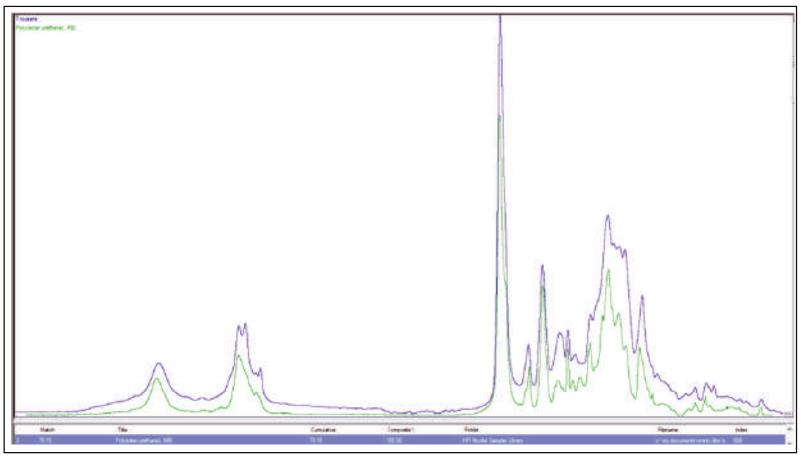

Fig. 7. FT-IR (ATR) spectra of trousers (blue) and the polyester urethane (database)

can be turned into threads and later into clothing items.
The trouser material was also a mixture of polyester and urethane, with an accuracy of 79.15%.

Colorimetric measurements

All six samples were exposed continuously for 24 hours to UV and visible light to simulate accelerated wearing in natural clothes. Colourimetric measurements were made before and after irradiation with a device that measures CieLAB parameters.
The colour parameters of the blue dress for children are presented in table 4.

Table 4

LAB PARAMETERS FOR THE BLUE DRESS

Sample	L*	a*	b*
D (Initial)	25.39	2.61	–16.53
D (visible light exposure)	25.91	2.83	–16.23
D (UV light exposure)	25.47	2.49	0.08

After visible light exposure, the colour parameters indicated that the colour of the blue dress sample decreased to 0.41% from the initial colour and 0.17% from the initial colour to the green colour (+a*).
After UV light exposure, the colour parameters indicated that 0.06% of the blue dress sample changed from the initial colour to white (+L*), to red (–a*), with a value of –0.09, and finally to yellow (+b*), with a value of 14.72. In this case, it can be concluded that UV light exposure produces a yellow shift in colour for the blue dress sample.
Table 5 shows the overall values of the colour parameters of the jeans overalls before and after exposure.
After visible light exposure, the colour of the jean overalls shifted to white (+L*) with a 2.05% change from the initial value, the green (+a*) value exhibited a 0.41% change from the initial value, and the yellow (+b*) value showed a 4.29% change from the initial value.
After UV light exposure, the colour of the jean overalls sample shifted to black (–L*) with a 3.04% change from the initial value, the red (–a*) shifted with a –0.18% change, and the blue (–b*) value shifted, with a –2.46% change from initial value.
The visible light exposure of the jean overalls produces a shift in yellow colour, and UV light exposure produces a shift in black and blue colours.

Table 5

LAB PARAMETERS FOR JEAN OVERALLS

Sample	L*	a*	b*
J (Initial)	67.4	–5.36	–4.84
J (visible light exposure)	70.84	–4.86	0.4
J (UV light exposure)	62.31	–5.58	–7.84

No colourimetric measurements were made for the white dress because of the colour.
The colour parameters for the belt are presented in table 6.
After visible light exposure, the colour parameters of the belt sample shifts to black (–L*) with a –0.83% change from the initial value, the red colour shifted

Table 6

LAB PARAMETERS FOR THE BELT SAMPLE

Sample	L*	a*	b*
B (Initial)	32.51	–1.56	–24.74
B (visible light exposure)	31.41	–3.55	–17.7
B (UV light exposure)	31.99	–1.62	–25.27

(–a*) with a –1.59% change from the initial value, and the yellow colour shifted (+b*) with a 6.88% change from the initial value.
After UV light exposure, the colour of the belt sample shifted to black (–L*) with a –0.39% change from the initial value, the red colour shifted (–a*) with a –0.05% change from the initial value, and the blue colour shifted (–b*) with a –0.52% change from the initial value.
Visible light exposure of the belt sample produced a yellow shift in colour, and UV light exposure produced black and blue shifts in colour.
Table 7 shows the values of the colour parameters of the trousers before and after exposure.

Table 7

LAB PARAMETERS FOR THE TROUSER SAMPLE			
Sample	**L***	**a***	**b***
T (Initial)	21.3	0.43	–0.61
T (visible light exposure)	24.13	0.3	–0.67
T (UV light exposure)	20.96	0.37	–0.59

After visible light exposure, the colour of the trouser sample shifted to white (+L*) with a +2.33% change from the initial value, the red colour shifted (–a*) with a –0.1% change from the initial value, and the blue colour shifted (–b*) with a –0.05% change from the initial value.
After UV light exposure, the colour of the trouser sample shifted to black (–L*) with a –0.28% change from the initial value, the red colour shifted (–a*) with a –0.05% change from the initial value, and the yellow colour shifted (+b*) with a +0.02% change from the initial value.
The visible light exposure of the trouser sample produced a shift of the colour toward white, and UV light exposure produced an insignificant colour shift.
The skirt sample colour parameters are presented in table 8.

Table 8

LAB PARAMETERS FOR THE SKIRT SAMPLE			
Sample	**L***	**a***	**b***
S (Initial)	22.03	–0.07	–0.49
S (visible light exposure)	25.68	–0.19	–1.14
S (UV light exposure)	22.53	–0.07	–0.57

After visible light exposure, the colour of the skirt sample shifted to white (+L*) with a +2.99% change from the initial value, the red colour shifted (–a*) with a –0.09% change from the initial value, and the colour shifted toward blue (–b*) with a –0.51% change from the initial value.
After UV light exposure, the colour of the skirt sample shifted to white (+L*) with a +0.41% change from the initial value, there was no red (–a*) shift in colour, and the colour shifted to blue (–b*) with a –0.06% change from the initial value.

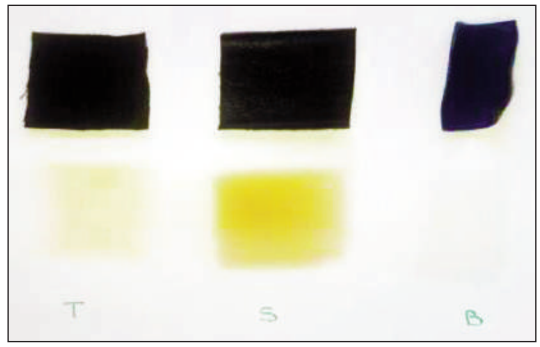

Fig. 8. Trouser, skirt and belt samples after 24 h of Vis exposure

The visible light exposure of the skirt sample produces a shift in colour toward white, and UV light exposure produces an insignificant colour shift.
An important detail that is worth noting is that after visible irradiation, all the polymeric samples stained the support paper they were placed on, as shown in figure 8.

CONCLUSION

This article aimed to characterise (phthalate and formaldehyde determination, FTIR measurements) the materials from which six clothing items are made and their behaviour under UV and Vis irradiation. The results showed that all of these materials contain dangerous phthalates, the white dress material for children contains an enormous amount of formaldehyde, the belt material is used for hose manufacture, and the "ecological leather" is a mixture of polymers. In addition, after UV and visible light exposure, the samples change and even stain the support paper. All these aspects lead to the conclusion that consumers must choose their clothes very carefully, especially those for children, because many of them, due to the materials they are made of, represent a real danger and should not come into contact with the skin.

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“Zero waste” – current and essential concept in the fashion industry

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ABSTRACT – REZUMAT

“Zero waste” – current and essential concept in the fashion industry

This article analyses the concept of “Zero Waste” in the fashion industry and highlights its current character and the need for its implementation. The aim of the paper is to examine the various strategies and benefits associated with adopting zero waste practices in the fashion sector in order to minimize the negative impact on the environment. The idea’s relevance is driven by growing global concerns about pollution and climate change, with the fashion industry considered one of the most polluting industries in the world. The main aim of the paper is to highlight the importance of adopting sustainable and innovative practices that will significantly reduce textile waste and promote a circular economy in this sector. The aim of the study process is to identify and analyse effective methods for implementing zero waste principles and to highlight the role of consumer education in maintaining these practices. As part of the research, concrete examples of designers and collections are presented that have successfully adopted these principles and demonstrate their feasibility as well as economic and ecological advantages. The information obtained as a result of the study process highlights the need for close collaboration between all stakeholders in the fashion industry to transform the way clothing is produced and consumed. The practical applications carried out by the authors demonstrate the possibility of obtaining models of current garments by applying modern design techniques using CLO 3D software. It highlights the fact that by applying innovative design and production practices, the fashion industry can become a model of sustainability, contributing to a more ecological and responsible future.

Keywords: *zero waste design, sustainability, sustainable processes in fashion, 3D prototyping, CLO 3D*

„Zero deșeuri” – concept actual și esențial în industria modei

Acest articol analizează conceptul de „zero deșeuri” în industria modei și evidențiază caracterul său actual, precum și necesitatea implementării acestuia. Scopul lucrării este de a examina diversele strategii și beneficiile asociate adoptării practicilor „zero deșeuri” în sectorul modei, în vederea minimizării impactului negativ asupra mediului. Relevanța acestei idei este determinată de îngrijorările globale tot mai accentuate cu privire la poluare și schimbările climatice, industria modei fiind considerată una dintre cele mai poluante industrii din lume.

Obiectivul principal al lucrării este de a evidenția importanța adoptării unor practici sustenabile și inovatoare care să reducă semnificativ deșeurile textile și să promoveze economia circulară în acest sector. Studiul urmărește identificarea și analiza unor metode eficiente de implementare a principiilor „zero deșeuri”, subliniind totodată rolul educației consumatorilor în implementarea acestor practici.

În cadrul cercetării sunt prezentate exemple concrete de designeri și colecții care au adoptat cu succes aceste principii, demonstrând fezabilitatea acestora, precum și avantajele economice și ecologice. Informațiile obținute în urma studiului evidențiază necesitatea unei colaborări strânse între toți actorii implicați în industria modei pentru a transforma modul în care sunt realizate producția și consumul de articolele vestimentare.

Aplicațiile practice realizate de autori demonstrează posibilitatea obținerii unor modele vestimentare actuale prin aplicarea tehnicilor moderne de design, utilizând CLO 3D. Se evidențiază faptul că, prin aplicarea unor practici inovatoare de proiectare și producție, industria modei poate deveni un model de sustenabilitate, contribuind la un viitor mai ecologic și responsabil.

Cuvinte-cheie: *industria modei, sustenabilitate, design „zero deșeuri, prototipare 3D, CLO 3D*

INTRODUCTION

The fashion industry, characterized by the rapid pace of change and excessive consumption, is recognized as one of the most polluting industries in the world. The large amount of toxic waste, including clothes that are not recycled or reused, ends up in landfills where they break down slowly, releasing microfibers and greenhouse gases. Fast fashion worsens this issue by driving rapid production and impulsive consumer behaviour, leading to more discarded items. In this context, the concept of sustainability in fashion refers to the adoption of practices that minimize this negative impact, encouraging responsible production, conscious consumption and efficient use of resources [1].

The concept of “zero waste” comes as one of the solutions to reduce the negative impact of the fashion industry by minimizing waste and optimizing the use of resources [2]. According to a report by the Ellen

MacArthur Foundation, if fashion industry adopted the principles of a circular industry, including zero waste, greenhouse gas emissions would be reduced by up to 44% [3]. Optimising patterns so that there is no leftover, using recycled materials and extending the life cycle of products through repairs and reuse are some tangible solutions. These strategies not only protect the environment, but also reduce costs and educate both producers and consumers to adopt a more responsible and sustainable behaviour.

GENERAL ASPECTS REGARDING THE APPLICATION OF "ZERO WASTE" TECHNIQUES IN THE FASHION INDUSTRY

Today's waste problems in the fashion industry have highlighted its ecological responsibility. From a sustainable design perspective, material conservation can be achieved by employing zero waste design methods.

By adopting "zero waste" design principles, important steps will be taken in the development of a sustainable textile industry. The benefits of this concept will become obvious when this is applied by all actors involved in the fashion industry – producers and consumers. For this purpose, it is necessary to establish the application strategies and benefits of zero waste techniques in the fashion industry.

By adopting innovative design practices, using sustainable materials, optimizing production processes and educating consumers, the fashion industry can significantly reduce its negative impact on the environment and become a model for sustainability for other industries [4].

Achieving the goal of "zero waste" in the textile industry is not an easy task, but it is highly important for a sustainable future. By adopting innovative practices, working closely with industry players and educating consumers, the way we produce and consume textiles can be transformed. The textile industry has the potential to become a model of sustainability, a responsible and ecological approach is possible and beneficial in the long term for all.

In order to obtain sustainable models, it is necessary to take into account the listed strategies and to establish the main stages of creating "zero waste" clothing items (figure 1).

By following the steps shown in figure 1, designers and manufacturers can create "zero waste" clothing designs that will not only have a beneficial impact on the environment by reducing textile waste, but will also promote sustainability and innovation in the fashion industry.

"ZERO WASTE" DESIGNERS AND METHODS

The concept of cutting clothes without generating waste is not a new technique. It is known that since ancient times clothing was made from whole pieces of material, its role being exclusively utilitarian at the beginning. The technique of creating Greek chitons and traditional Indian sari, which involves using fabric without stitches to produce draped (fabric manipulation) garments, offers a way to make clothes without wasting any material [7, 8].

In contemporary society, clothing has not only a utilitarian role, but also an aesthetic one. Hence the need to create models of clothing products of complex shapes and cuts. Designers such as Holly McQuillan, Timo Rissanen, Stella McCartney, etc. are known for the sustainable techniques applied to the creation of clothing collections. They aim to minimize waste through design methods that effectively use every piece of material. Through precise cutting techniques and the design of ingenious patterns, "zero waste" designers considerably reduce the negative impact on the environment. Instead of being thrown away, leftover materials are integrated into new creations [9], turning waste into valuable resources.

Table 1 presents the names and strategies of designers who have implemented sustainable techniques in their collections.

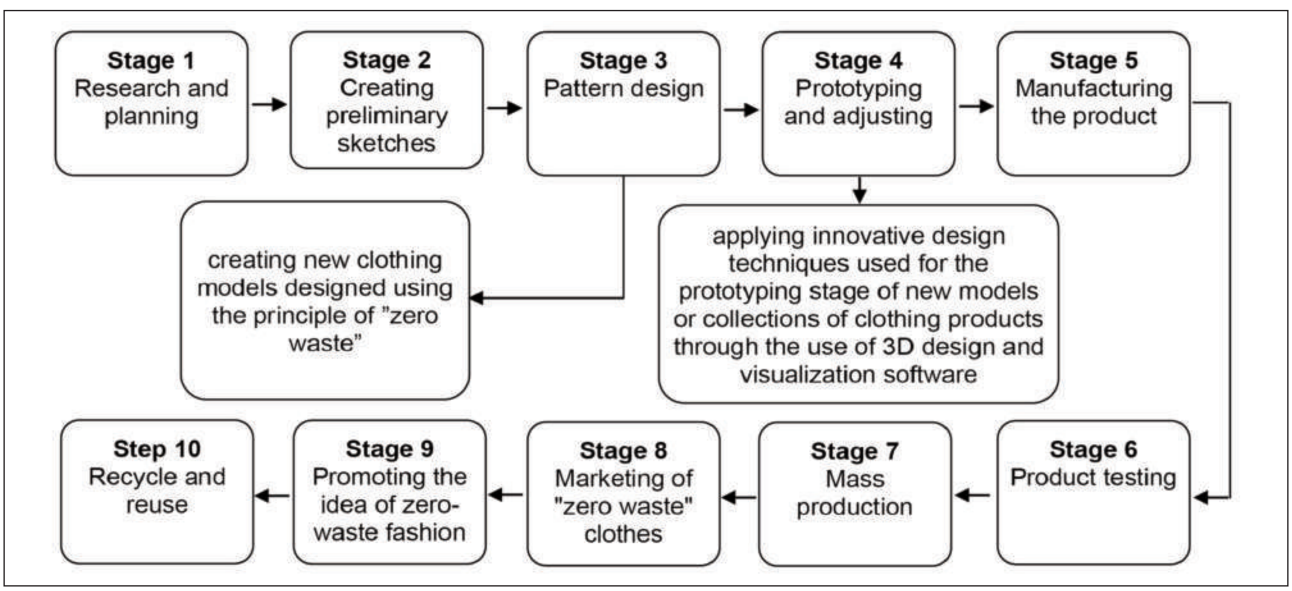


Fig. 1. The phases of the "Zero Waste" process [5, 6]

Table 1

EXAMPLES OF ZERO WASTE DESIGNERS	
Designers	**Techniques and strategies adopted**
Timo Rissanen [10]	He has dedicated his career to the research and development of design techniques that reduce material waste. His works include complex and elegant pieces created in the puzzle technique. Through methods such as cutting with efficient patterns and precise fitting of pieces, the designer proves that sustainable fashion can also be aesthetically pleasing.
Holly McQuillan [11]	It uses techniques such as cut-and-sew and digital design to create clothes that produce no material waste. It also explores the use of organic and biodegradable textiles, ensuring that each garment is sustainable throughout its life cycle.
Daniel Silverstein [12]	His brand "Zero Waste Daniel" creatively repurposes textile remnants and pre-consumer, post-production materials to craft unique garments. Amid rising worries about excessive waste and pollution in fashion, Daniel transforms textile scraps into unique and vibrant pieces of clothing. By using small pieces of fabric that would otherwise have been thrown away, they create patchwork designs that are not only sustainable, but also extremely attractive. It also promotes consumer awareness of the impact of textile waste and the importance of reusing materials.
Camilla Carrara [13]	She founded the Italian brand Zerobarracento, a brand dedicated to the production of clothing without waste. Each collection is created using zero-waste tailoring techniques and sustainable materials such as recycled wool and organic silk. Minimalist design focused on clean and timeless lines proves that sustainable fashion can be stylish and versatile.
Kit Willow [14]	She promotes ethical and sustainable fashion. She implements zero-waste techniques in its collections and uses eco-friendly materials such as organic cotton and regenerated silk. She also focuses on transparency and accountability in the supply chain, ensuring that every step of the production process is sustainable.
Charlotte Bialas [15]	Charlotte Bialas incorporates vintage textiles and utilizes zero-waste geometrical cutting techniques to significantly minimize fabric waste. Any leftover scraps are creatively repurposed into accessories like necklaces, bags, or sashes.
Bojana Draca [16]	Founder of the Farrah Floyd brand, she tackles the technique of cutting textiles into rectangles of different sizes and joining them according to the principle of a grid.

The creations of pioneering designers in the world of sustainable fashion not only reduce the impact on the environment, but also inspire other fashion designers to adopt environmentally friendly techniques.

Through their commitment to green practices, they inspire positive change in the fashion industry and encourage consumers to make more responsible choices. The contribution of both the fashion designer and the consumer serves to achieve the common global goal of having a cleaner planet where nothing goes to waste.

By creating zero-waste models, designers express their desire to minimize the negative impact of fashion on the environment. Zero-waste techniques (cutting, draping, folding) or using scrap materials focus on optimizing materials, reducing material losses in the production process, and recycling or reusing materials creatively.

"Zero waste" methods in fashion represent an innovative and sustainable approach aimed at minimizing the waste generated during the entire production cycle of a textile product [17].

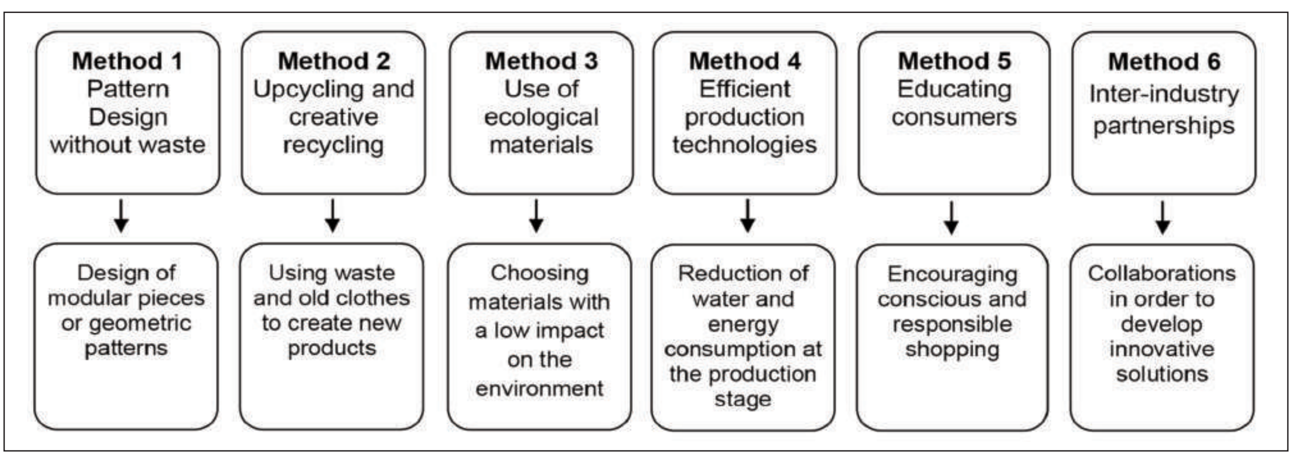


Fig. 2. "Zero waste" methods

In order to exclude some waste-generating technologies, it is necessary to adopt methods of making sustainable clothing models (figure 2).

By individually or collectively applying the methods presented in figure 2 these will contribute to the development of a durable and sustainable fashion industry.

PRACTICAL APPLICATIONS REGARDING THE CREATION OF CLOTHING USING THE "ZERO WASTE" PRINCIPLE

Zero waste fashion design advocates for the simultaneous improvement of fashion design and pattern making processes. The goal of zero waste pattern pieces is to use every inch of fabric, thus eliminating cut-and-sew waste by the end of the fashion production process.

As per [18–19], the difficulty of transforming 2D designs into 3D forms, which frequently leads to uneven results, is an obstacle to the industrial adoption of zero-waste fashion. This issue gives rise to potential application for 3D modelling software such as 'CLO', which is capable of accurately simulate the behaviour of materials in a realistic 3D garment [20]. According to McQuillan [21], implementing 3D software systems will facilitate the industry's transition to zero-waste practices. The author proposed modifying the zero-waste design process by eliminating the requirement for multiple design and pattern revisions between the initial concept and the sample through the use of 3D software.

In this part, digital resources have been used to test the pattern drafting method and simulating the end result within the 3D space. We aimed to investigate methods for eliminating textile waste in clothing production by designing three distinct zero waste fashion garments. By using the CLO 3D virtual fashion software, patterns have been both digitally and manually drafted and nested in order to minimize the waste and the garments were simulated.

It is well known that during the cutting process, a significant amount of fabric waste, ranging from 10 to 15 percent, is generated due to various factors, including marker efficiency, marker planning, and the garment's style. Garment patterns are composed of different shapes, such as curved corners and straight lines. When these patterns are laid out on a marker plan, gaps may appear, resulting in cut-and-sew waste [22].

The development of the zero waste patterns drafting technique involves creating an initial set of classic patterns that serve as the base in terms of shape and dimensions. This classic pattern set facilitates a final comparison of fabric usage and marker efficiency among the types of patterns.

In this study, the "zero waste" concept is a process that can be divided into several main stages. Figure 3 shows the component steps used by the authors to create models using this concept.

In the first stage of the process, the initial data needed to design the product collection were established. The initial data used are user and product data. There were included the values of the anthropometric dimensions of the wearer's body, body shape, product type, material type, etc. In the case of designing clothing products using the "zero waste" principle, an important aspect is the correct selection of textile materials. It is necessary that they present the same visual appearance on both the warp and the weft, so as to allow the placement of markers without taking into account certain framing standards.

The second stage included the creative process that aimed to create the models of the collection. Models can be developed by hand drawing or using various specialized software, such as Adobe Photoshop, Corel Draw, etc. In this work, the details of each model differ in both length and configuration. It was taken into account that the patterns must be designed so that the pieces of clothing fit together like a puzzle without leaving any unused spaces. Also, some markers on the front and back are identical because they can help reduce material waste through proper positioning.

In the third stage, the material was selected virtually from the software library, material similar to the real one. When choosing the virtual material, its visual and physical characteristics must be taken into account, so that they are as close as possible to those of the real material.

The fourth stage was carried out using the prototyping tools of the CLO 3D software. Designing the markers in 2D windows allows for the necessary details to be obtained that can be arranged in a manual frame. Simultaneously with this process, the model on the avatar's body can be viewed in the 3D window (figure 4).

Each model represents a different number of details. The number of details must be optimized in such a way as to allow obtaining an effective framing from the point of view of the use of materials, without negatively influencing the duration of the technological

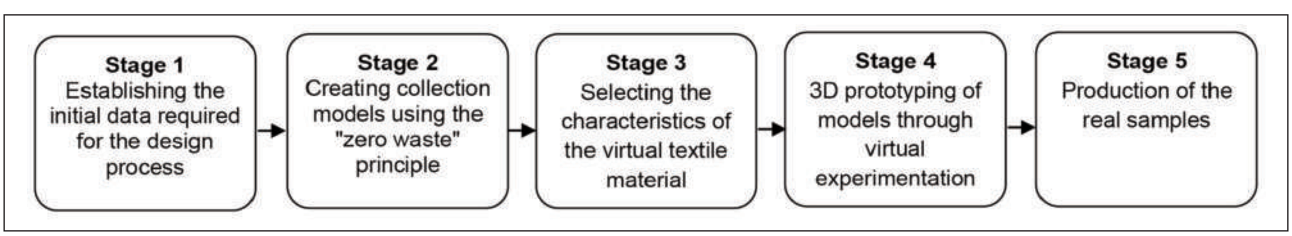


Fig. 3. The stages of the collection development process using the "zero waste" principle

Fig. 4. The models in the collection

process. Table 2 shows the components of the structure of the collection models in which their markers can be identified.

The fifth stage is the stage of actually making the collection models. The markers will be cut taking into account the manual framing, on the material selected in stage 1.

Next, it is presented the comparative analysis of the framing done manually and automatically of the collection models (table 3).

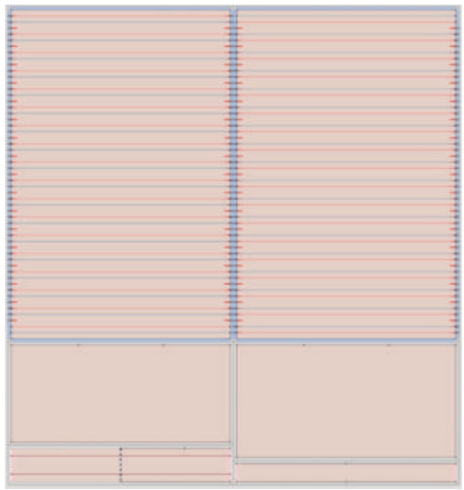
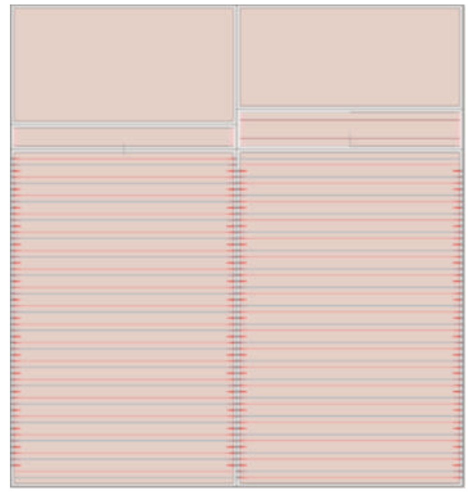
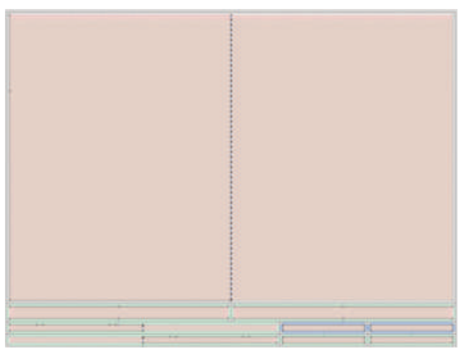
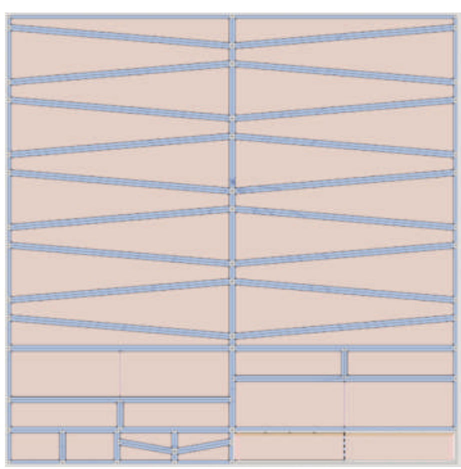
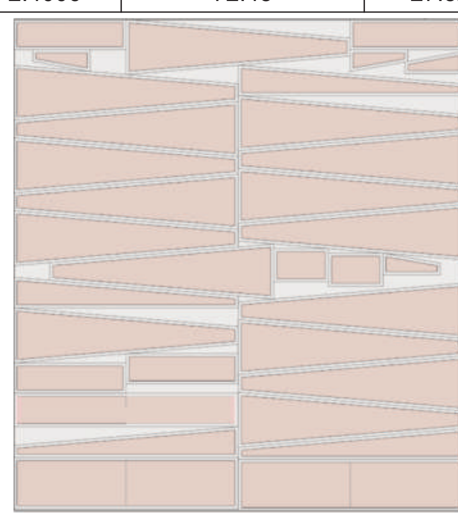
Considering the analysis of the models made in the practical part of this paper, it can be noticed:

1. 100% efficiency in the case of manual framing according to the puzzle principle. This aspect helps us save textile materials and respectively reduce the negative impact on the environment, but it will lead to increasing the time needed for creating the models and making the frames.
2. Automatic framing shows very good results in the case of rectangular markers (efficiency 100% – model 1), but in the case of markers of complex

Table 2

THE COMPONENTS OF THE COLLECTION MODEL STRUCTURE			
No./ The analysed criterion	**Model 1**	**Model 2**	**Model 3**
Representation of front elements			
Representation of back elements			
The number of elements	6	7	33

Table 3

FRAMING THE MODEL PARTS						
No./ The analysed criterion	**Manual framing**			**Automated framing**		
	Framing area, m^2	**Maximum efficiency of the framing, %**	**Framing wastes, %**	**Framing area, m^2**	**Maximum efficiency of the framing, %**	**Framing wastes, %**
1	**2**	**3**	**4**	**5**	**6**	**7**
Model 1	2.3236	100	0	2.3236	100	0
						
Model 2	1.6280	100	0	1.7212	86.18	13.82
						
Model 3	2.1909	100	0	2.4006	72.48	27.52
						

shape, the waste surface increases (efficiency 86.18% – model 2, efficiency 72.48% – model 3).

3. In the case of markers of more complex shapes, it is recommended to make additional divisions, but not to complicate the technological process extensively.
4. When making models by applying pattern design principles so that all textile surfaces are used, it is recommended to keep into account the specific attributes of the chosen fabric, including its usability and printed designs.

5. The examples of the models created in this work prove that it is possible to create modern clothing without waste, in addition, the use of CLO 3D design software excludes the consumption of textile materials during the prototyping stages.

CONCLUSIONS

The application of the "zero waste" concept in the fashion industry is not just a transitory trend, but a necessity in the context of the current ecological challenges. By reducing waste and using resources responsibly, the fashion industry will contribute significantly to reducing the negative impact on the environment. This approach meets the demands of consumers aware of the importance of sustainability and offers economic opportunities by optimizing resources and reducing production costs.

The studies and examples presented in this paper demonstrate that the application of the "zero waste" concept can significantly reduce textile waste. Through the collaboration between designers, producers and consumers, and by the use of advanced technologies, the fashion industry can achieve the goal of "zero waste", becoming a model of sustainability for other sectors.

Further research directions will be considered:

- the development of the model collection according to the established principles and its actual production;
- the development of new projection methods based on the "Zero Waste" principle;
- the development of collections using the modular method.

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Financial awareness and financial planning among higher education faculty and their specific impact on the financial literacy of aspiring textile entrepreneurs

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ABSTRACT – REZUMAT

Financial awareness and financial planning among higher education faculty and their specific impact on the financial literacy of aspiring textile entrepreneurs

Financial awareness among citizens is directly related to the economic growth of the country. With increasing investor education programmes by financial regulators like the Reserve Bank of India (RBI) and the Securities and Exchange Board of India (SEBI), financial literacy among Indian youth and adults has witnessed significant growth. Despite this, still, only less than one-third of the nation can fulfil the minimum criteria of financial literacy as laid down by the RBI. So, there is a need to understand different aspects of financial awareness and how it impacts different areas of financial planning. This empirical study attempts to study the financial awareness and financial planning of higher education faculty in Mumbai from India, with the thought that teachers have high influential power, and financially aware teachers can produce financially responsible citizens who can contribute significantly to the economic growth and sustainable development of the nation. Textile entrepreneurs require strong financial literacy to navigate business decisions and ensure long-term success. Financially aware faculty can serve as role models and equip aspiring textile entrepreneurs with the knowledge and skills needed to thrive. The results of the empirical analysis reveal that overall mean scores for financial knowledge and retirement & estate planning are lower than other constructs. The output of ANOVA suggests that there exists a significant difference in financial awareness and financial planning of teachers belonging to different specialisation domains. Regression analysis shows that the financial awareness level significantly affects the financial planning score of teachers.

Keywords: *financial awareness, financial planning, financial literacy, teachers, higher education, textile entrepreneurs*

Conștientizarea financiară și planificarea financiară în rândul cadrelor didactice din învățământul superior și impactul specific al acestora asupra educației financiare a antreprenorilor aspiranți în domeniul textil

Conștientizarea financiară a cetățenilor este direct legată de creșterea economică a țării. Odată cu creșterea programelor de educație financiară de către autoritățile de reglementare financiară precum Reserve Bank of India (RBI) și Securities and Exchange Board of India (SEBI), alfabetizarea financiară în rândul tinerilor și adulților din India a cunoscut o creștere semnificativă. În ciuda acestui fapt, doar mai puțin de o treime din națiune este capabilă să îndeplinească criteriile minime de alfabetizare financiară, așa cum sunt stabilite de RBI. Prin urmare, este nevoie să înțelegem diferite aspecte ale conștientizării financiare și modul în care aceasta influențează diferite domenii ale planificării financiare. Acest studiu empiric încearcă să analizeze conștientizarea financiară și planificarea financiară a cadrelor didactice din învățământul superior din Mumbai, India, pornind de la ideea că profesorii au o putere de influență ridicată, iar profesorii conștienți financiar pot forma cetățeni responsabili din punct de vedere financiar, care pot contribui semnificativ la creșterea economică și dezvoltarea sustenabilă a țării. Antreprenorii din domeniul textil au nevoie de o alfabetizare financiară solidă pentru a lua decizii de afaceri și a asigura astfel succesul pe termen lung. Facultatea conștientă financiar poate servi drept model și poate dota aspiranții antreprenori din domeniul textil cu cunoștințele și abilitățile necesare pentru a prospera. Rezultatele analizei empirice arată că scorurile medii generale pentru cunoștințele financiare și planificarea pensionării și a succesiunii sunt mai mici decât alte constructe. Rezultatul analizei ANOVA sugerează că există o diferență semnificativă în ceea ce privește conștientizarea financiară și planificarea financiară a profesorilor aparținând diferitelor domenii de specializare. Analiza de regresie arată că nivelul de conștientizare financiară afectează semnificativ scorul de planificare financiară al profesorilor.

Cuvinte cheie: *conștientizare financiară, planificare financiară, alfabetizare financiară, profesori, învățământ superior, antreprenori din industria textilă*

INTRODUCTION

Financial planning is very important for a successful and financially strong lifestyle. An effective financial plan gives an edge over risks and losses at the time of need. Being financially aware allows you to meet your life goals and fulfil your dreams. Financially aware citizens with proper financial planning will

boost domestic savings and the growth of the economy.
India ranked 23rd in the VISA 2012 Global Financial Literacy Barometer out of 28 markets. The study highlighted that India's saving rates are the highest among other global peers, but the awareness about investments is very less among Indian households. 24% of the population is financially literate as of 2020. It shows the importance of promoting financial awareness in India.
Teachers have a highly influential power, and they can positively contribute to many people's lives. By knowing financial planning, they can become role models to students and aspiring textile entrepreneurs, enabling a country to produce financially responsible citizens; this, in turn, can contribute significantly to the GDP growth of the country. Financially aware teachers can conduct workshops for individuals interested in starting small textile businesses like tailoring units or handloom cooperatives. This would empower these individuals financially and potentially create new job opportunities within the textile sector.
Thus, this study attempts to examine financial awareness and financial planning among higher education faculty in Mumbai. The objective of the study is to examine teachers' awareness level in liquidity management, investments, savings, borrowings, insurance, and retirement planning. It further examines the impact of financial awareness on personal financial planning.

Need for the study

Financial literacy statistics of India have not been very promising. The chart given below depicts the comparison of financial literacy in developed and emerging countries.
The chart in figure 1 signifies that financial literacy in India is lower than in most of the advanced and emerging economies. Thus, there is a need to give a good pace to our efforts in financial education and inclusion. The financial stability of an individual depends upon financial attitude and behaviour, which in turn depends upon financial awareness and appropriate financial planning. Teachers play an instrumental role in shaping young minds towards a secure future. Teachers come in regular contact with students, and therefore, they can act as the most appropriate agents of social change and help our country in achieving one of the major macroeconomic goals of financial inclusion.
The success of any financial education policy majorly depends on those who are educating students, who ultimately determine the future of any nation. Thus, their financial awareness and planning should be good. The existing research is an attempt to study the financial awareness level of higher education teachers in Mumbai and how it affects their financial planning.

REVIEW OF LITERATURE

Financial awareness

OECD (2013) [1] states that financial literacy comprises an individual's ability, awareness, behaviour, attitude, and knowledge required to make sound financial decisions, thereby contributing to financial well-being. Therefore, the important factors to analyse financial awareness include financial knowledge, financial attitude, and financial behaviour.
Bhushan and Medury [2] concluded that to enhance financial literacy across generations, it is crucial to prioritise the cultivation of positive financial mindsets within people. By doing so, we can fully unlock the advantages of any financial education initiative.
Atkinson and Messy [3] state that engaging in positive financial practices, such as effective budgeting and maintaining financial stability, contributes to enhancing financial literacy. Conversely, engaging in detrimental financial behaviours, such as excessive reliance on credit and loans, undermines overall financial well-being.
Sages and Grable [4] found that individuals who possess a limited tolerance for financial risk encounter challenges when making financial choices and experience dissatisfaction with their ability to manage money effectively. This illustrates the interconnectedness between one's financial mindset and financial

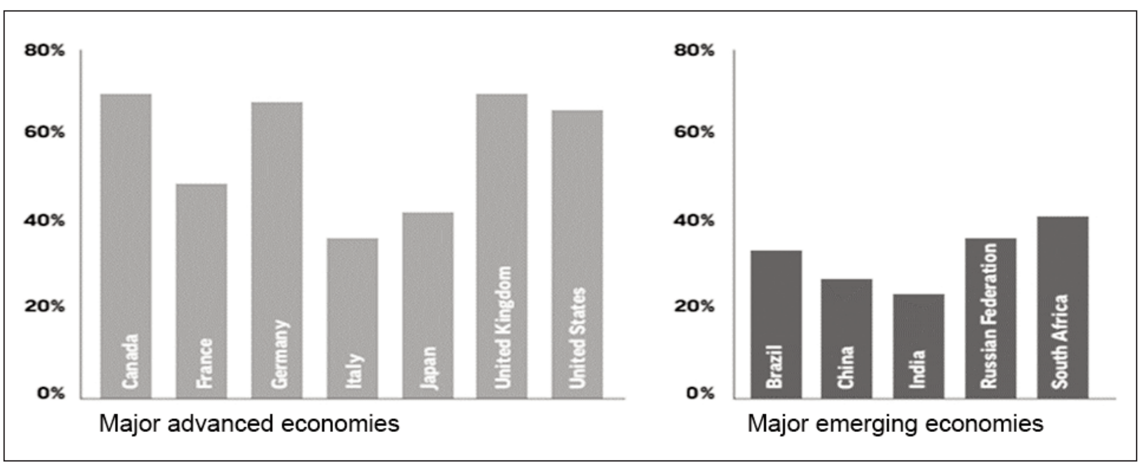

Fig. 1. Financial Literacy Global Statistics (*Source:* S&P Global FinLit Survey)

behaviour. Lusardi et al. [5] state that women with low financial literacy are not much involved in retirement planning and heavily rely on their family and friends for financial and investment decisions. In a study conducted by Mathavathani and Velumani [6] focusing on rural women in Tamil Nadu, it was discovered that financial literacy levels among this group are notably inadequate. Bonga et al. [7] raised concerns regarding increasing the financial literacy of women, especially in economically weaker nations. Their research suggests that increasing women's financial literacy has the potential to bring about enduring shifts in behaviour. Kumar et al. [8] found that better financial literacy improves an individual's financial inclusion behaviour. Frank et al. [9] identified a strong link between financial awareness and retirement planning within textile workers, which leads to improvement in savings attitude. This study also highlighted the importance of seminars and workshops in improving retirement savings attitudes.

Demographic impact on financial literacy

Joyce et al. [10] found that the financial awareness level of males is higher in comparison to females among youths in Malaysia. Agarwal [11] discovered that male respondents have a higher likelihood of providing accurate responses in terms of financial literacy compared to female respondents. Furthermore, this probability increases in correlation with the individual's level of education and their assertiveness. Dwivedi et al. [12] showed that men and women possess differing degrees of financial literacy. Men exhibit a higher comprehension of financial matters compared to women. Conversely, women display a more favourable financial attitude in terms of behaviour and knowledge, while men tend to have a less favourable financial attitude in comparison. Syal [13] states that women investors have a limited understanding of financial services. The majority of women investors continue to put their money in safe and established investment routes, indicating that they are risk-averse. Agarwal [11] found that Indians have less financial understanding than people in other countries. He also noted that men's financial awareness is somewhat lower than women's. Trivedi and Trivedi [14] found that males, urban residents, and higher-income groups are more aware of financial information. Financial literacy is unaffected by marital status.

Singh and Kumar [15] highlighted that low financial literacy is connected to decreased household savings. Women, the less educated, low-income groups, ethnic minorities, and elderly respondents are more likely to be financially illiterate.

Mittal and Vyas [16] discovered that investors of all ages are sceptical of mutual funds and debentures/bonds as investment avenues. In terms of occupation, they discovered that persons in the service class like to invest in stocks and mutual funds, while those belonging to the business class exhibit a preference for investing in debentures/bonds and assets such as real estate/bullions. Post office savings and derivatives are commonly favoured investment options among professionals, whereas housewives choose secure assets such as real estate/bullion. High-risk assets, such as derivatives and stocks, are preferred by youth.

Mohini and Veni [17] state that general education greatly boosts investment, income, and retirement savings in the domain of personal financial planning. However, it may not provide one with the necessary information and competence for making investment decisions. Financial knowledge alone at a young age, primarily at the school/college level, aids in household financial planning.

Chturwedi and Khare [18] investigated the impact of age, education, employment, and income level on investment and discovered characteristics that influence investor awareness and choice. The study found that an investor's age has no bearing on their degree of knowledge, and that the investor's gender has no bearing on their level of awareness regarding any investment channel.

Srinivasan et al. [19] assessed working women's financial understanding in India, and the findings of the study showed that respondents had a sound understanding of investment and personal financial planning issues and were eager to make personal finance investment decisions.

Salter et al. [20] state that gender, education, wealth, and debt are all linked to the usage of financial consultants. The use of advisors was also linked to an increase in planning activities, awareness, and confidence.

Anshika and Singla [21] state that the progress of an economy's financial system is dependent on financial literacy. As the number of financial goods and services increases, financial literacy is becoming increasingly important. In 2015, India's financial literacy level was 24 percent, which was quite low in comparison to other countries. The country's economic growth is hampered by a lack of financial literacy.

Kumar and Gandhi [22] emphasised financial literacy among members of counselling centres and also investigated how well qualified they are to make financial decisions. It also focuses on their desire to obtain information about financial management. Financial management is sound in both men's and women's families. Married households are better able to handle their own money than single, unmarried households. The respondents' educational qualifications assist their capacity to handle finances; yet, the salaried class has greater financial management competence than the other occupational sectors.

Arianti et al. [23] showed that educational age is favourably related to financial literacy; the level of education does not have a relationship with financial literacy, whereas income level demonstrates a positive correlation with financial literacy. Fernandes et al. [24] identified the attributes of financial behaviour that have the potential to influence policy decisions, serving as effective tools for promoting and supporting consumer financial behaviour.

Financial awareness of teachers

Nkrumah [25] conducted a study on teachers in Ghana and found that the financial literacy level of teachers is inadequate, which negatively impacts their productivity as they are worried about financial challenges. Kapoor et al. [26] discovered that a good number of teachers faced difficulties in comprehending financial concepts such as interest, loan terminology, and the importance of paying credit card bills on time. Research indicates that having financial awareness has a beneficial impact on personal financial management.

Deng et al. [27] emphasised that elementary school textbooks fail to adequately foster financial management knowledge among elementary school students. This suggests that the existing financial education curricula in Taiwan are not suitable for elementary school teachers and their students. However, Awais-E-Yazdan et al. [28] also mentioned the impact of the COVID-19 pandemic on employees' behaviour and its complex implications. Spulbar et al. [29] investigated the impact of financial education on textile industry development. Moreover, Sumera et al. [30] also examined the effect of education on per capita income in the context of the COVID-19 pandemic.

Research gaps identified

Upon reviewing the literature, it was evident that extensive research has been conducted on topics such as financial awareness, financial education, and their influence on individual financial well-being. However, there is a limited number of studies specifically focusing on teachers' financial planning and financial literacy. Additionally, no studies were found that directly compare the financial awareness and financial planning of higher education faculty.

Teachers play a pivotal role in society, acting as influential figures who shape the future of students. Their own financial awareness and personal financial planning are essential for effectively educating students to become responsible citizens in matters of finance and society. It is often believed that teachers with backgrounds in finance and commerce possess high levels of financial literacy and excel in financial planning. Therefore, there is a need to examine the extent of financial awareness among teachers and investigate how it influences their financial planning. This research endeavour will contribute to our understanding of the correlation between financial awareness and financial planning.

RESEARCH METHODOLOGY

Objectives of the study

The objectives of the current study are the following:

- To investigate the financial awareness level among higher education faculty in Mumbai.
- To analyse the effect of financial awareness of teaching staff on financial planning.
- To examine whether there is any difference in financial awareness and financial planning for different demographics like gender, educational background, and specialisation domain.

Research design

This study could be classified as Descriptive and Exploratory. It is descriptive as it seeks to analyse financial awareness levels of teachers with different genders, education qualifications, specialisation, etc. It is exploratory as it analyses the impact of financial awareness in financial planning through a detailed statistical analysis.

Research problem

This study attempts to study financial awareness and financial planning among higher education teachers in Mumbai. The objective of the study is to examine teachers' awareness level in managing money, investments & savings, borrowing, insurance and retirement planning. It further examines the impact of financial awareness on personal financial planning.

Figure 2 presents the theoretical model of the study. Figure 2 indicates the different variables studied in the current research. Variables like Financial Knowledge, Behaviour and Attitude are used to compute Financial Awareness. Each of the variables is computed using different statements on a five-point Likert scale.

Variables like Tax Planning and Budgeting, Managing Liquidity, Protection of Life and Assets, Funding Large Purchases, Savings & Investments, Retirement and Estate Planning are used to compute the Financial Planning Score.

Correlation and Regression analysis are conducted to study the effect of financial awareness on the financial planning of higher education teachers in Mumbai.

Sampling

Population universe

For conducting this study, the universe is the teaching staff working in higher education institutes in Mumbai.

Sampling technique

The sampling technique used in this study is Random Sampling, comprising data collected from 123 respondents. Thus, the outcomes of this study are expected to have broader implications and relevance for the entire teaching staff, encompassing teachers from various disciplines. The findings will provide valuable insights and understanding that can be beneficial for enhancing financial awareness and personal financial planning among educators across different subject areas.

Hypothesis formulation

Based on the literature review and proposed research model, the following hypotheses are formulated:

H01: *There is no statistically significant difference* in financial awareness scores and financial planning scores based on the selected demographic factors.

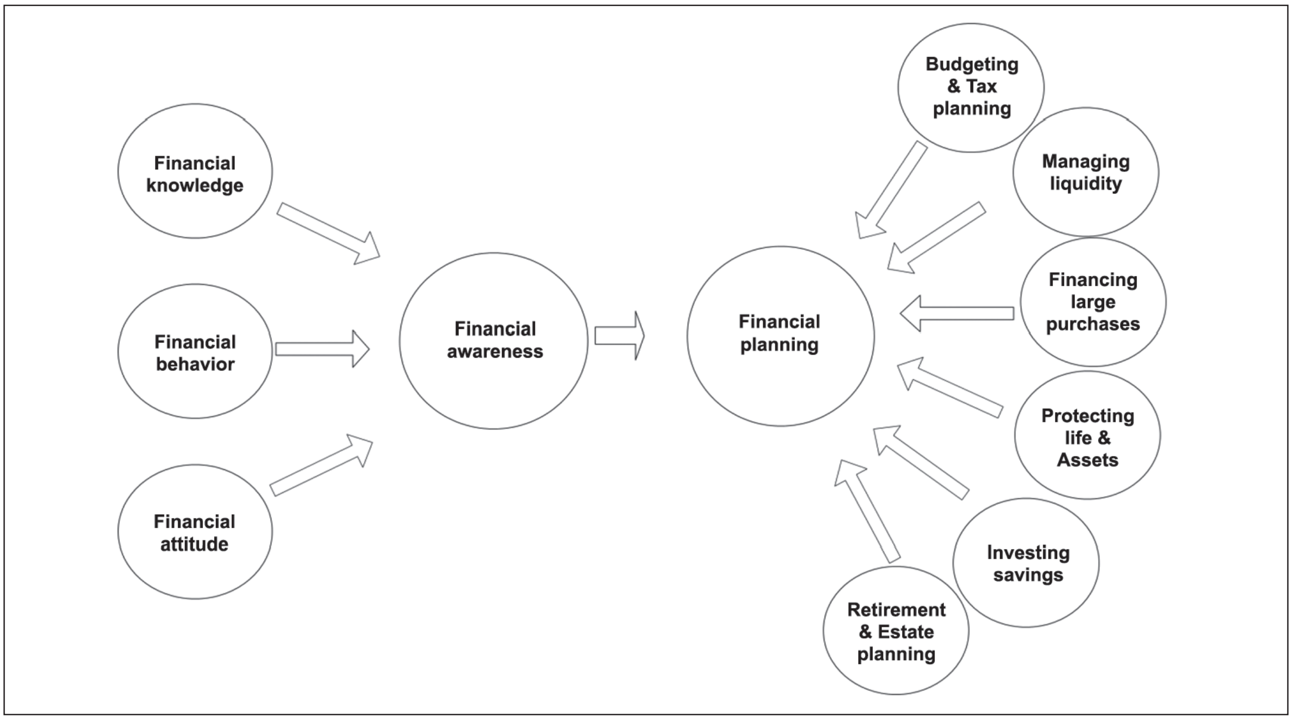

Fig. 2. Theoretical model of the study

H02: *There is no statistically significant relationship* between financial awareness scores and financial planning scores.

Tools of analysis

Correlation is used to study the relationship between financial awareness and financial planning.

Regression is used to study whether financial planning scores are significantly influenced by the level of financial awareness.

Anova is used to study the significant difference in financial awareness and financial planning concerning selected demographic variables.

Limitations of the study

Teachers of higher education in Mumbai are considered for the present study. So, the findings and conclusions of the present study may not be generalised to other people's financial awareness and planning.

The current study is limited to selected variables, and the results of the study do not include the complete financial and investment behaviour of the respondents.

DATA ANALYSIS AND INTERPRETATION

Cronbach's Alpha to test the reliability of the scale

As Cronbach's Alpha is more than 0.7 for both latent variables, the scale used in the questionnaire is reliable, and the Likert statements used are internally consistent (table 1).

Descriptive statistics of constructs

As can be seen in table 2, the average financial awareness score of respondents is 79.15% with a standard deviation of 9.99%, and the average financial planning score is 76.23% with a standard deviation of 10.02%.

ANOVA

ANOVA to test the significant difference in financial planning score and financial awareness level of male and female members

HO1(a): There is no significant difference in the financial awareness score and the financial planning score of male and female teachers

As the p-value is more than 0.05, the null hypothesis is accepted. Therefore, financial awareness and financial planning of male and female teachers are similar (table 3).

Table 1

SPSS OUTPUT OF CRONBACH'S ALPHA TEST

Variable	Cronbach's Alpha	Cronbach's Alpha based on standardised items	N of items
Financial Awareness	0.827	0.844	16
Financial Planning	0.918	0.925	31

Table 2

SPSS OUTPUT FOR DESCRIPTIVE STATISTICS OF CONSTRUCTS					
N		**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Financial Knowledge Score	123	50.00	100.00	85.8542	11.61265
Financial Behaviour Score	123	40.00	100.00	82.0163	12.60106
Financial Attitude Score	123	36.00	100.00	69.5935	16.69585
Budgeting &Tax planning Score	123	32.00	100.00	79.7724	12.56903
Managing Liquidity Score	123	24.00	100.00	79.9024	13.26119
Financing Large Purchases Score	123	40.00	100.00	76.3902	11.53657
Protecting Life and Assets Score	123	33.33	100.00	77.3711	13.19781
Investing Savings Score	123	36.00	100.00	73.9512	12.50695
Planning Retirement and Estate Score	123	32.00	100.00	70.0984	13.53991
Financial Awareness Score	123	52.67	100.00	79.1544	9.99942
Financial Planning Score	123	40.11	97.33	76.2311	10.02597
Valid N (listwise)	123				

Table 3

SPSS OUTPUT FOR ANOVA TO TEST SIGNIFICANT DIFFERENCE IN FINANCIAL AWARENESS AND FINANCIAL PLANNING BASED ON GENDER						
Sum of Squares			**df**	**Mean Square**	**F**	**Sig.**
Financial Awareness Score	Between groups	269.696	1	269.696	2.736	0.101
	Within groups	11928.885	121	98.586		
	Total	12198.581	122			
Financial Planning Score	Between groups	48.732	1	48.732	0.483	0.489
	Within groups	12114.192	120	100.952		
	Total	12162.923	121			

Table 4

SPSS OUTPUT FOR ANOVA POST HOC BASED ON GENDER			
Gender		**Financial Awareness Score**	**Financial Planning Score**
Female	Mean	80.4643	75.6679
	N	69	68
	Std. Deviation	9.39878	9.93052
Male	Mean	77.4806	76.9404
	N	54	54
	Std. Deviation	10.57049	10.19338
Total	Mean	79.1544	76.2311
	N	123	122
	Std. Deviation	9.99942	10.02597

As can be seen in the descriptive statistics in table 4, the average financial awareness score and average financial planning score of male and female teachers are similar.

ANOVA to test the significant difference in financial planning score and financial awareness level of teachers with different educational qualifications

HO1(b): There is no significant difference in the financial awareness score and the financial planning score of teachers with different educational qualifications.

Thus, the null hypothesis is accepted as the p-value is higher than 0.05, suggesting that there is no significant difference in financial awareness and financial planning among higher education faculty with varying educational qualifications (table 5).

Table 5

SPSS OUTPUT FOR ANOVA TO TEST SIGNIFICANT DIFFERENCE IN FINANCIAL AWARENESS AND FINANCIAL PLANNING BASED ON EDUCATION QUALIFICATION						
Sum of Squares			**df**	**Mean Square**	**F**	**Sig.**
Financial Awareness Score	Between groups	317.537	3	105.846	1.060	0.369
	Within groups	11881.044	119	99.841		
	Total	12198.581	122			
Financial Planning Score	Between groups	284.309	3	94.770	0.941	0.423
	Within groups	11878.614	118	100.666		
	Total	12162.923	121			

As can be seen in the descriptive statistics in table 6, the average financial awareness score and average financial planning score of teachers with different qualifications are similar.

Table 6

SPSS OUTPUT FOR ANOVA POST HOC BASED ON EDUCATION QUALIFICATION			
Education qualification		**Financial Awareness Score**	**Financial Planning Score**
Graduate	Mean	72.0000	80.0000
	N	1	1
	Std. Deviation	**0.00**	**0.00**
Post-Graduate	Mean	78.6744	75.3574
	N	87	87
	Std. Deviation	10.27426	10.93542
Doctorate	Mean	81.3619	77.9784
	N	31	31
	Std. Deviation	8.31564	7.18893
Post-Doctorate	Mean	74.2750	82.2600
	N	4	3
	Std. Deviation	15.58149	4.69166
Total	Mean	79.1544	76.2311
	N	123	122
	Std. Deviation	9.99942	10.02597

ANOVA to test the significant difference in financial planning score and financial awareness level of teachers with different specialisation domains

HO1(c): There is no significant difference in the financial planning score and financial awareness level of teachers with different specialisation domains.

As the p-value is less than 0.05, H0 is rejected, indicating a significant difference in financial awareness and financial planning among teachers with different specialisation domains (table 7).

As can be seen in the descriptive statistics in table 8, the average financial awareness score and average financial planning score of teachers with finance specialisation are higher compared to teachers with non-finance specialisation.

Correlation to test the relationship between financial awareness and financial planning

HO2(a): There is no significant relation between financial awareness and the financial planning score of higher education faculty in Mumbai

Since the correlation coefficient is 0.657, there exists a positive relation between financial awareness and financial planning score. Since the p-value is less than 0.05, the correlation coefficient is statistically significant and therefore the null hypothesis is rejected (table 9).

Table 7

SPSS OUTPUT FOR ANOVA TO TEST SIGNIFICANT DIFFERENCE IN FINANCIAL AWARENESS AND FINANCIAL PLANNING BASED ON SPECIALIZATION DOMAIN						
Sum of Squares			**df**	**Mean Square**	**F**	**Sig.**
Financial Awareness Score	Between groups	609.237	1	609.237	6.361	0.013
	Within groups	11589.344	121	95.780		
	Total	12198.581	122			
Financial Planning Score	Between groups	434.696	1	434.696	4.448	0.037
	Within groups	11728.227	120	97.735		
	Total	12162.923	121			

Table 8

SPSS OUTPUT FOR ANOVA POST HOC BASED ON SPECIALIZATION DOMAIN			
Specialization domain		**Financial Awareness Score**	**Financial Planning Score**
Finance	Mean	81.3619	78.0881
	N	62	62
	Std. Deviation	9.79859	10.08544
Non-Finance	Mean	76.9107	74.3123
	N	61	60
	Std. Deviation	9.77462	9.67572
Total	Mean	79.1544	76.2311
	N	123	122
	Std. Deviation	9.99942	10.02597

Table 9

SPSS OUTPUT FOR CORRELATION ANALYSIS BETWEEN FINANCIAL AWARENESS AND FINANCIAL PLANNING			
Financial Awareness Score	Pearson Correlation	1	0.657**
	Sig. (2-tailed)		0.000
	N	123	122
Financial Planning Score	Pearson Correlation	0.657**	1
	Sig. (2-tailed)	0.000	
	N	122	122

Note: **Correlation is significant at the 0.01 level (2-tailed).

Table 10

SPSS OUTPUT FOR REGRESSION ANALYSIS TO STUDY THE IMPACT OF FINANCIAL AWARENESS ON FINANCIAL PLANNING				
Variable	**Coefficient**	**T-Value**	**P-Value**	**Adjusted R^2**
Intercept	24.250	4.421	0.000	0.432
Financial Awareness Score	0.656	9.551	0.000	

Note: Dependent Variable: Financial Planning Score.

Regression analysis to test the effect of financial awareness level on financial planning score

HO2(b): There is no significant impact of financial awareness level on financial planning score.

The null hypothesis is rejected as the p-value is less than 0.05, suggesting a significant relationship between the financial awareness score and the financial planning score (table 10).

The regression equation is the following:

$$\textit{Financial Planning Score } (Y) = 24.250 + 0.656 * \textit{Financial Awareness Score } (X)$$

Adjusted R-squared value of 0.427 suggests that the regression model is a good fit [29] and the financial awareness level explains 42.7% of the variation observed in the financial planning score.

FINDINGS AND CONCLUSIONS

Despite various investor education programmes by financial regulators like the RBI and SEBI, the training in personal financial planning in India is still at a nascent stage. Irrespective of one's specialisation domain, personal finance education is an inseparable part of the learning process. Thus, this study shows the different aspects of financial awareness and financial planning.

The detailed analysis depicts that higher education teachers in Mumbai have an average financial awareness level of 79.1544% and a financial planning score of 76.2311. Compared to other aspects, the average score of financial attitude and estate planning is lower. Based on the ANOVA analysis, the results indicate a significant difference in financial awareness and financial planning scores between teachers with a finance domain and those without a finance domain. The correlation and regression analysis demonstrate that financial awareness has a significant impact on financial planning.

The findings of this study underscore the urgent need for comprehensive financial literacy programs specifically designed for higher education faculty in India. By equipping faculty members with robust financial knowledge and planning skills, educational institutions can empower them to serve as effective role models and mentors for future entrepreneurs, including textile entrepreneurs. This, in turn, can contribute substantially to the growth, sustainability, and competitiveness of the textile industry, as well as the overall economic development of the nation.

The results of this study also offer valuable insights for policymakers, regulators, and educational institutions designing financial literacy programs for higher education faculty. Financially informed faculty can nurture a generation of textile entrepreneurs who make sound financial decisions, navigate business challenges effectively.

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Analysis of yielding during the tensioning of fabrics in plain and four-wire twill weave

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ABSTRACT – REZUMAT

Analysis of yielding during the tensioning of fabrics in plain and four-wire twill weave

The deformation properties of woven textile materials depend on several factors. The main factors are the physical and mechanical properties of the yarn, the weave of the fabric and the density of the warp and weft in the fabric. The paper analysed the parameters at the yield point during tensioning of fabrics with different densities of weft wires, different weft yarns, with applied plain weave and four-wire twill weave. A special problem for predicting the deformation characteristics of textile materials is their anisotropic properties, so the results were analysed in the direction of the warp, in the direction of the weft and the diagonal direction.

A comparative analysis of the parameters at the yield point of fabrics in plain weave and four-wire twill weave, produced on the same basis in the weaving process, is given. Based on the obtained results, dependencies were proposed that can be used to predict the yielding of the corresponding fabrics in plain weave and four-wire twill weave, when the fabric is stretched in the direction of the warp, in the direction of the weft and at an angle of 45°.

Keywords: *fabric, plain weave, twill weave, force, elongation, yielding of material*

Analiza elasticității țesăturilor cu legătură pânză și legătură diagonal în patru fire

Proprietățile de deformare ale materialelor textile țesute depind de mai mulți factori. Principalii factori sunt proprietățile fizice și mecanice ale firului, legătura țesăturii și densitatea firelor de urzeală și de bătătură în țesătură. Lucrarea a analizat parametrii la punctul de elasticitate în timpul întinderii țesăturilor cu densități diferite ale firelor de urzeală, fire de urzeală diferite, cu legătură pânză și legătură diagonal în patru fire. O problemă specială pentru prezicerea caracteristicilor de deformare ale materialelor textile o reprezintă proprietățile lor anizotrope, astfel încât rezultatele au fost analizate în direcția urzelii, în direcția bătăturii și în direcția diagonală.

Este prezentată o analiză comparativă a parametrilor la punctul de elasticitate a țesăturilor cu legătură pânză și legătură diagonal în patru fire, produse pe aceeași bază în procesul de țesere. Pe baza rezultatelor obținute, au fost propuse dependențe care pot fi utilizate pentru a prezice elasticitatea țesăturilor corespunzătoare cu legătură pânză și legătură diagonal în patru fire, atunci când țesătura este întinsă în direcția urzelii, în direcția bătăturii și la un unghi de 45°.

Cuvinte-cheie*: țesătură, legătură pânză, legătură diagonal, forță, alungire, elasticitatea materialului*

INTRODUCTION

Mechanical characteristics represent a complex of properties that determine the ability of woven materials to resist the action of various external forces that can cause various types of deformation (shearing, compression, tension, twisting, bending, etc.).

Changes in the shape of woven materials occur as a result of the action of external forces. Deformation of the material depends on the type, direction, intensity, time of force action and relaxation time. Changes in the shape of textile material cause disruption of the structure of woven materials [1–3]. More significant changes in the structure of woven materials occur at the moment when the tension force in intensity exceeds the value of the force at the yield point [4].

Woven textile materials are characterised by anisotropic properties, which represent a special problem when predicting their mechanical characteristics [5, 6]. New methods and devices have been developed for measuring the mechanical characteristics of fabrics [7–9] to explain the changes in the shape of the woven material during use. The effect of changing the weft density on the fabric thickness during stretching was analysed in paper [10].

In addition, methods have been developed for predicting the breaking forces of fabrics and changes in sample dimensions until breaking [11, 12]. In the paper [13], a mechanical model was developed using which can calculate Poisson's ratio through the stress-strain curve of the fabric.

Also, the influence of the anisotropy was analysed of the fabrics in the plain weave on the constants of elasticity in different directions [14]. Also, some papers investigate the tensile behaviour of fabrics with elastane in the stretching process. The deformation of woven materials with different percentages of elastane yarns was analysed [15–17].

However, a review of the literature reveals a lack of data on methods for determining limit loads that can cause significant deformations of fabrics. Therefore, the paper presents a method that can be applied to determine the limit values of the load. The method is based on the analysis of the flow of the force-elongation function and defining the limit up to which the material offers significant resistance to the tensile force, that is, until the moment when the material begins to yield.

In practice, a conclusion is often made about the quality of a fabric (mechanical properties) only based on its breaking characteristics, which is not enough to obtain real information about the material. The values of force and elongation at the yield point of fabrics give a true picture of the permissible loads to which textile materials can be subjected without being significantly deformed.

MATERIALS AND METHODS

The mechanical properties of 40 different fabrics were analysed, 20 in plain weave (Plain 1/1) and 20 in four-wire twill (Twill 3/1). The fabrics are produced in industrial conditions, on a weaving machine with electronic regulation of the weaving process, using yarns from a mixture of PES/Co 50/50% fibres.

All 40 fabrics were produced on the same warp, linear density 25×2 tex (break – 1157 cN; elongation – 8.5%; twist – 600 m^{-1}), with a warp density of 27 cm^{-1}. For the weft are used yarns with a linear density of 25x2 tex (break – 1157 cN; elongation – 8.5 %; twist – 600 m^{-1}), 50 tex (break – 1033 cN; elongation – 9.3 %; twist – 520 m^{-1}), 41.67 tex (break – 807 cN; elongation – 8.8 %; twist – 551 m^{-1}) and 29.41 tex (break – 609 cN; elongation – 6.9 %; twist – 630 m^{-1}), with densities for each weft; 14 cm^{-1}, 16 cm^{-1}, 18 cm^{-1}, 20 cm^{-1} and 22 cm^{-1}.

The breaking characteristics of the fabrics were measured on a dynamometer, MesdanLab Strength Tester, Standard ISO 13934/1 [18]. The speed of stretching until the break of the fabric sample is 100 mm/min. In addition, data were recorded based on which force-elongation dependences were obtained for all analysed fabrics in the direction of the warp, in the direction of the weft and the direction of the diagonal and approximated in the corresponding functions of polynomials of the 9th degree.

Based on the analysis of the flow of the force-elongation function, the yield limit was defined for all 40 fabrics in the direction of the warp, in the direction of the weft and the direction of the diagonal. The maximum of the first derivative of the force-elongation function (the second derivative of the function equal to zero) defines the yield limit [4]. At a given maximum of the first derivative of the function, the data for force and elongation at the yield point were recorded.

RESULTS AND DISCUSSION

When the fabric is loaded, there are changes in its structure that are conditioned by the intensity, direction and time of the force, as well as the fabric's construction solution. Changes in fabric structure at low loads occur as a result of mastering and redistribution of warp and weft crimp. By further increasing the tension force, resistance to stretching is provided by the fibres in the yarn, which elongate in the direction of the force until the moment when the resistance of the frictional force between the fibres is overcome, i.e. when slippage between the fibres occurs and the material loosens. By further increasing the tensioning force, resistance is provided by the yarns that stretch and at the same time bear the pressure of the other yarn system, until they break. The transition from one phase to phase does not mean that the deformations from the previous phase stop. The straightening of the wires in the direction of the force, as well as the sliding between the fibres, continues until the break. Dislocations of the wires occur in the diagonal direction during the stretching of the samples, which is especially expressed in fabrics with a lower density of weft wires [4].

To objectively observe the influence of the change in weft density on the force at the yield point of the analysed fabric samples, all other constructional and structural parameters must be equal (raw material composition, linear density of warp and weft, weave, warp density). Therefore, all analysed fabrics were made on the same warp. Based on the obtained test results, histograms were created, which show the influence of the density of weft wires on the values of force and elongation of fabrics at the yield point in the three observed directions. The results for fabrics are grouped on the histograms, so that the influence of the density of the weft wires, as well as the influence of the applied weave on the deformation properties of the fabrics, with other parameters being equal, can be seen. The corresponding colours indicate the type of weft yarn, and the influence of the applied weft yarn on the force and elongation values at the yield point of the analysed fabrics can be seen.

Figure 1 shows the influence of weft density on the values of force and elongation at the yield point of fabrics in the direction of the warp for 20 fabrics with applied plain weave and for 20 fabrics with applied four-wire twill weave of the warp effect.

Based on the obtained results, it is not possible to see a clear influence of the density of the weft wires on the force values at the yield point of fabrics with applied plain and four-wire twill weave. If the influence of the wave is observed, with other parameters being unchanged, in the majority of cases, fabrics with applied plain weave have higher force values at the yield point in the direction of the warp (figure 1, *a*). The elongation at the yield point in the direction of the warp increases with the increase in the density of the warp wires (figure 1, *b*). This statement applies to all analysed fabrics. Also, it can be noted that the elongation at the yield point in the direction of the warp in fabrics with applied plain weave is greater than in fabrics with applied four-wire twill weave, other parameters being unchanged. By analysing the obtained results, it can be observed that the linear density of the weft has an influence on the value of

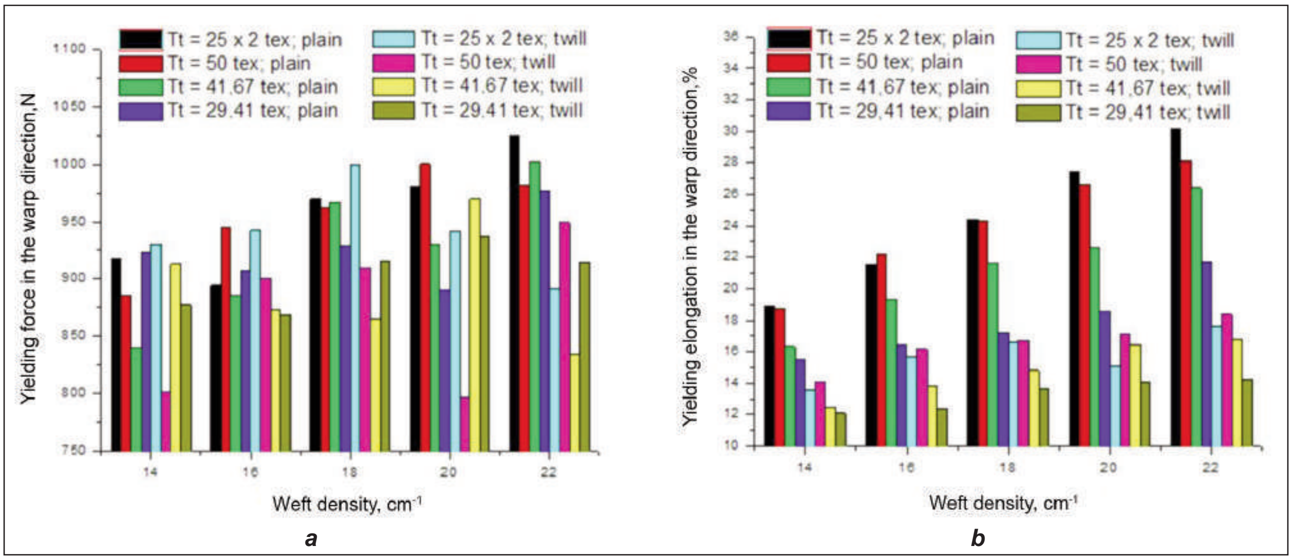

Fig. 1. Influence of weft density and weave on: *a* – force; *b* – elongation at the yield point of the fabric in the direction of the warp

the elongation at the yielding limit of the fabric in the direction of the warp. The crimp of the warp, in addition to other parameters, has a significant influence on the elongation value in the direction of the warp. Raw fabrics with applied plain weave have a higher warp crimp compared to fabrics with applied four-wire twill weave [19]. Also, the crimp of the warp increases with the increase in the density of the weft wires, but also with the use of thicker yarns for the weft, which is one of the reasons for the elongation values obtained in this way at the limit of yielding in the direction of the warp.

The influence of the density of the weft wires and the applied weave on the deformation properties of the fabrics in the direction of the weft is shown in figure 2. The obtained results show that the density of the weft wires has a direct influence on the value of the force at the yield point of fabrics with applied plain and four-wire twill weave (figure 2, *a*). Also, the results show that the force values at the yield point of the fabrics in the direction of the weft are higher in fabrics with applied plain weave compared to fabrics with applied four-wire twill weave. This is the expected result, since the number of changes in wire effects about the pattern repeat is greater in fabrics with applied plain weave [20], and therefore, the contact surface between the warp and weft yarns is larger, which contributes to the strength of the fabric.

Figure 2, *b* shows the influence of the weft density on the elongation value at the yield point of the fabric in the weft direction. The results show an increasing trend of elongation at the yield point in the direction of the weft, with an increase in the density of the weft wires, for all analysed fabrics.

Figure 3 shows the results of the force and elongation values at the yield point of the fabrics in the diagonal direction for all forty samples. A certain trend of increasing force at the yield point is observed

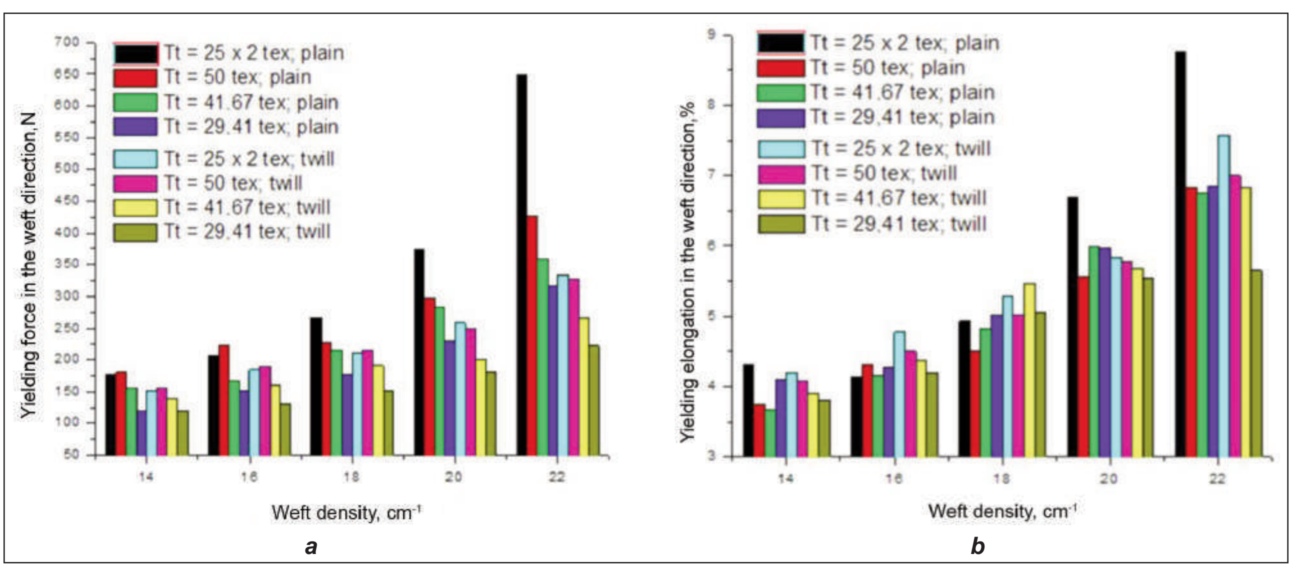

Fig. 2. Influence of weft density and weave on: *a* – force; *b* – elongation at the yield point of the fabric in the direction of the weft

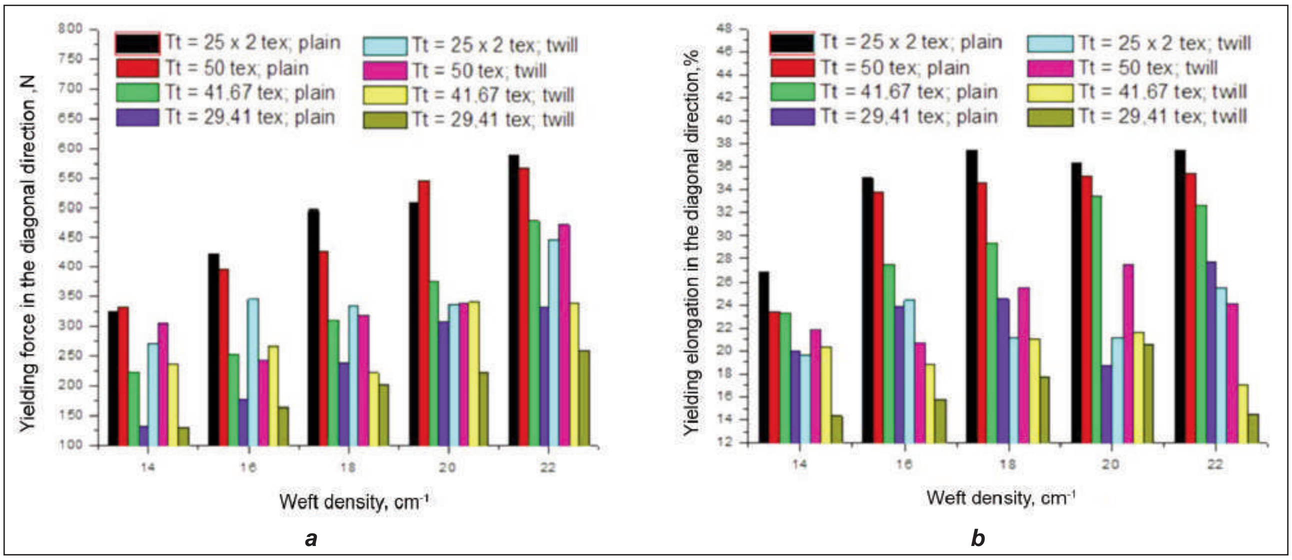

Fig. 3. Influence of weft density and weave on: *a* – force; *b* – elongation at the yield point of the fabric in the diagonal direction

for fabrics with a higher density of weft wires, while no clear influence of weft density on elongation at the yield point of fabrics in the diagonal direction can be observed.

Based on the obtained results, it can be concluded that the fabrics with the applied plain weave have higher force values at the yield point in the diagonal direction. Also, fabrics with applied plain weave have a greater elongation at the yield point in the diagonal direction compared to fabrics with applied four-wire twill, other parameters being unchanged.

The mechanical properties of weft yarns generally have the expected influence on the properties of fabrics at the yield point. Namely, the smallest force values at the yield point in the direction of the weft and in the direction of the diagonal have fabrics with an applied weft of linear density 29.41 tex.

Breaking force and breaking elongation of the fabric are important parameters that characterise the mechanical properties of the material. However, data on these parameters are not sufficient to obtain a true picture of the mechanical properties of the woven material. Textile materials suffer various loads during exploitation. From the point of view of preserving the structure of woven material, it is very important to have data on the limit loads to which a material can be subjected without its properties being impaired. That is why the limit values of load in the direction of the warp, the direction of the weft and in the diagonal direction have been determined for all fabrics. By analysing the flow of the force-elongation function, the yield point was determined, which represents the load limit up to which a material can be loaded without being deformed.

Figure 4 shows the values of the force participation at the yield point about the breaking force of the fabric. The percentage of participation of the force at the yield point in the breaking force in the direction of the warp in fabrics with applied plain weave is in the range of 62.5–71.5 %, while in fabrics with applied four-wire twill weave, it is 57.9–75.7 %. The increase in the density of the weft wires in the fabric contributes to the increase in the percentage of the force at the yield point in the breaking force in the direction of the weft, in the range of 25.2–51.8 % for plain weave, while for four-wire twill it is 23.5–40.4 %, and this growth is especially pronounced when the values are analysed in the diagonal direction, where the range of results for plain weave is 37.5–84.4 %, and for four-wire twill 57.6–85.1 %. An increase in the density of the weft wires contributes to an increase in friction between the warp and weft wires, due to a greater number of connecting points of the warp and weft per unit area, so the material provides greater resistance to wire slippage when the fabric is tensioned and stretched. In addition, if the influence of the applied weave on the percentage of force participation at the yield point in the breaking force is analysed, it is observed that these results are higher for fabrics with applied plain weave in the direction of the weft, with other parameters being unchanged.

Figures 5, 6 and 7 show graphs of the relationship between elongation at break and elongation at yield point in warp direction, weft direction and diagonal direction for all analysed fabrics.

The relationship between elongation at the yield point (the maximum of the first derivative of the force-elongation function) and breaking elongation (data measured on a dynamometer) is shown by an equation of the form $y = a + bx$.

Table 1 shows the correlation dependence parameters for all three directions for the analysed fabrics with applied plain and four-wire twill weave.

By applying the obtained data, it is possible to determine the elongation limit values of the corresponding woven materials with the applied plain and four-wire twill weave from the 50% PES/50% Co fibre mixture. As the force-elongation dependence is defined for

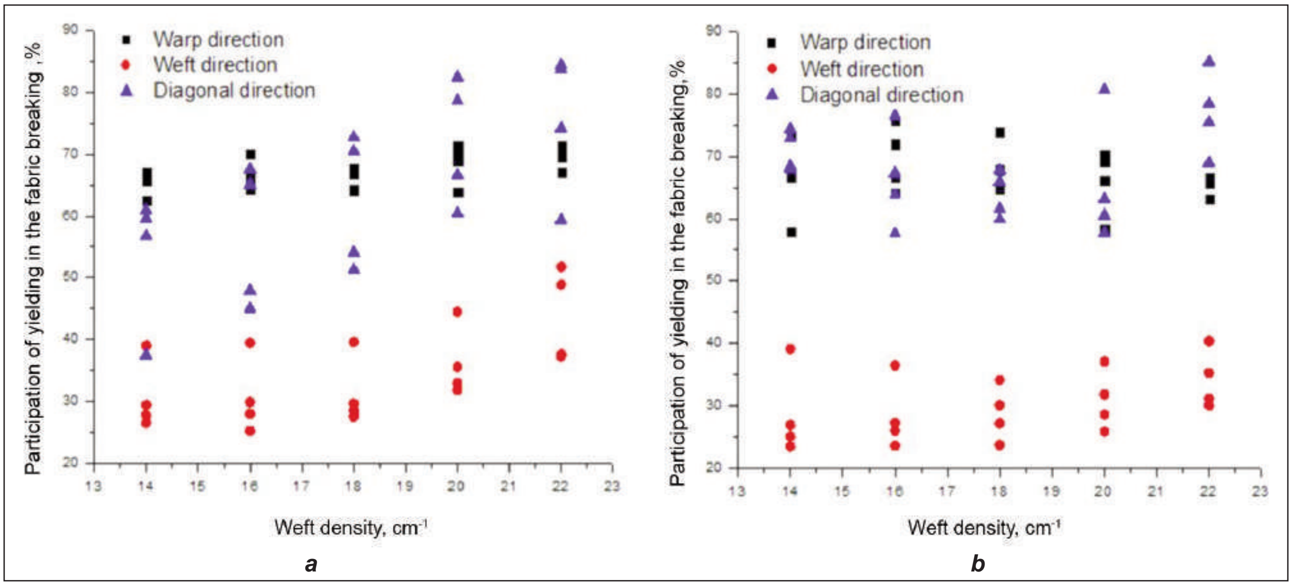

Fig. 4. The percentage of the force at the yield point in the breaking force of the fabric with the applied:
a – plain; *b* – four-thread twill weave

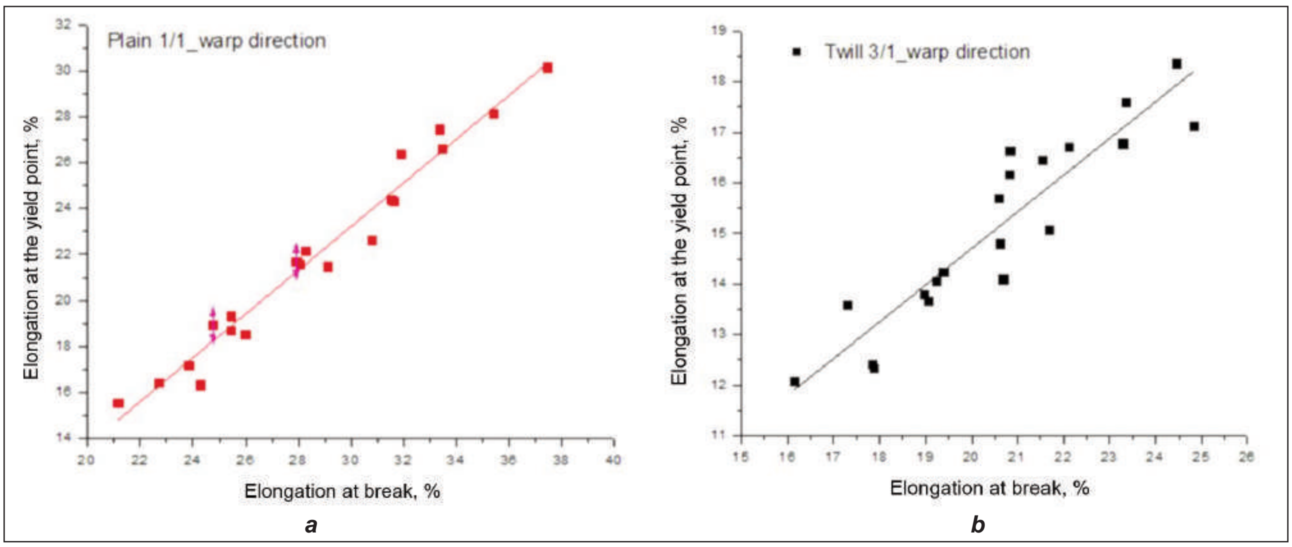

Fig. 5. Relationship between elongation at the yield point and breaking in the warp direction, fabric in:
a – plain weave; *b* – twill weavee

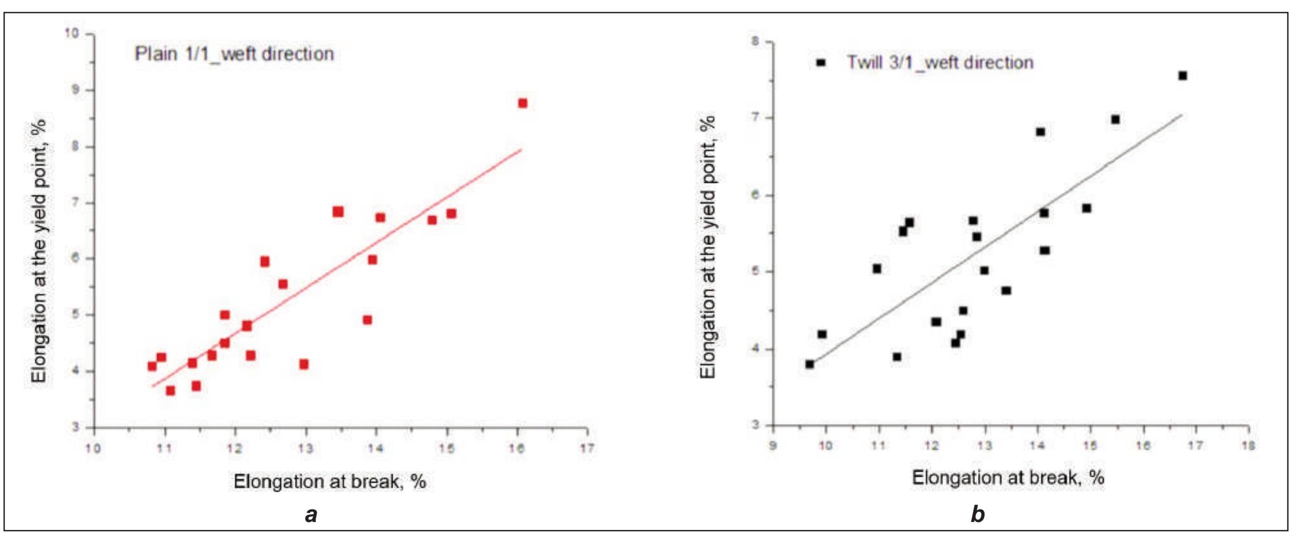

Fig. 6. Relationship between elongation at the yield point and breaking in the direction of the weft direction, fabric in:
a – plain weave; *b* – twill weave

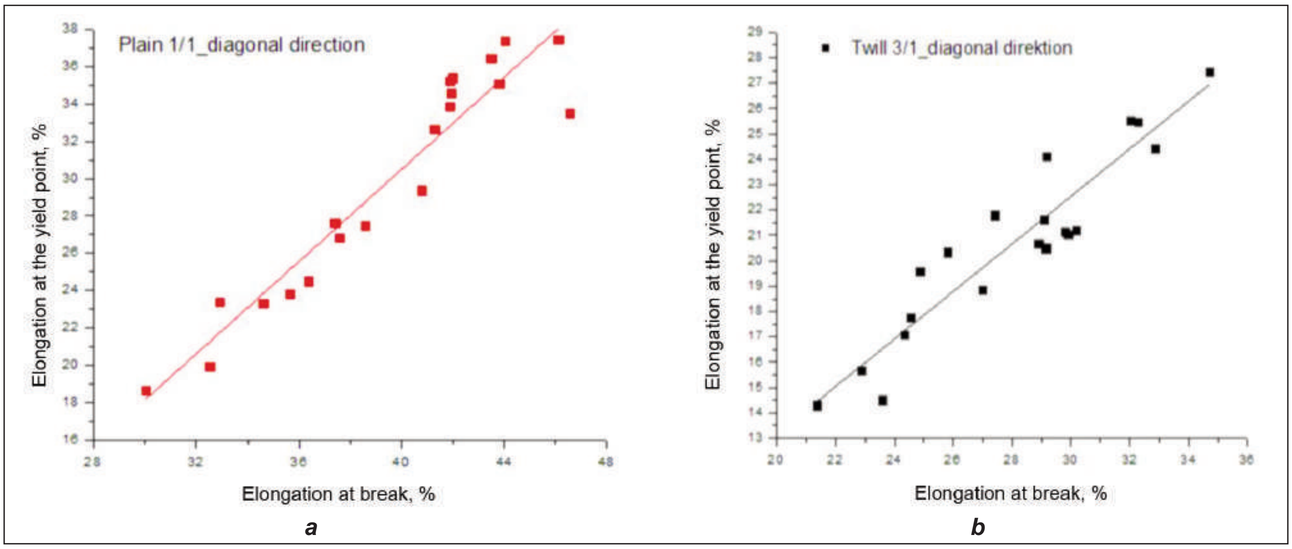

Fig. 7. Relationship between elongation at the yield point and breaking in the diagonal direction, fabric in: *a* – plain weave; *b* – twill weave

Table 1

CORRELATION DEPENDENCE PARAMETERS					
Function	*y = a + bx*				
	Plain weave				
Parameters	a	St.error	b	St.error	r^2
Warp direction	–5.352	1.138	0.953	0.039	0.967
Weft direction	–4.991	1.273	0.806	0.099	0.773
Diagonal direction	–18.826	3.668	1.233	0.092	0.903
	Twill weave 3/1				
Parameters	a	St.error	b	St.error	r^2
Warp direction	0.200	1.433	0.725	0.069	0.851
Weft direction	–0.696	1.127	0.463	0.087	0.588
Diagonal direction	–5.581	2.314	0.937	0.082	0.872

each sample in the form of a ninth-degree polynomial, it is easy to determine the value of the force at the yield point at the corresponding elongation.

CONCLUSIONS

By increasing the density of the weft wires in the fabric, the force at the yield point of the fabric increases in the weft direction and has a growing trend in the diagonal direction. Also, elongation at the yield point increases in the direction of the warp and the direction of the weft.

Fabrics with applied plain interlacing have higher values of elongation at the yield point in the direction of the warp and in the diagonal direction, and generally higher values of force at the yield point compared to fabrics with applied four-wire twill weave.

The deformations of woven materials depend on their structure, construction, and the intensity and direction of the load. Defining the parameters of fabrics at the yield point and relating them to breaking characteristics can serve to develop a method for predicting the behaviour of fabrics during exploitation. Also, the obtained data can be useful for optimising the structure and construction of woven materials according to their future purpose.

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Antimicrobial treatment based on green silver nanoparticles applied to textile heritage

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ABSTRACT – REZUMAT

Antimicrobial treatment based on green silver nanoparticles applied to textile heritage

Nanomaterials science expanded its application in various directions (biomedical, smart materials, sensors, optoelectronics, etc.). Silver nanoparticles (AgNPs) have been intensively tested within the textile department and demonstrated antimicrobial activity when applied under various forms (commercial colloidal nano-silver, in situ synthesis, etc.). The application of silver nanoparticles for historical artefacts conservation has been addressed, and several papers have reported the use of such treatments for cultural heritage conservation. In this work, the historical sample tested consisted of a cotton fabric, part of a priest's costume, dating back to the 18th century, provided by the Church of Saint Nicolae "Dintr-o Zi", located in Bucharest. The piece was treated with AgNPs-based treatment, which was phyto-synthesised by using a plant aqueous extract. The effect of the treatment on the sample was examined by studying fibres of the fabrics with electronic microscopy (SEM) and by quantifying the modification of the sample appearance, using chromatic parameters measurements. The antimicrobial activity was tested against gram-positive and gram-negative bacteria strains, Escherichia coli and Staphylococcus aureus, and the fungal strain Penicillium hirsutum. The layer of silver nanoparticles was uniformly distributed on the surface of the historical textile fibres. The changes in the appearance of the textile were minimal, with a total colour difference of 2.11. Evaluating the antimicrobial activity, superior antifungal performance was observed against the Penicillium hirsutum strain (for which the inhibition zone value was 12.5 mm). The FTIR spectrum demonstrated that the integrity of the textile fibre is maintained following the application of the treatment.

Keywords: *silver nanoparticles, conservation treatment, historical textiles*

Tratament antimicrobian pe bază de nanoparticule de argint „green” aplicate pe materiale textile de patrimoniu

Știința nanomaterialelor și-a extins aplicația în diverse direcții (biomedicală, materiale inteligente, senzori, optoelectronice etc.). În cadrul departamentului de textile, nanoparticulele de argint (AgNPs) au fost testate intens și au demonstrat activitate antimicrobiană, atunci când sunt aplicate sub diferite forme (nano-argint coloidal comercial, prin sinteză in situ etc.). Aplicarea nanoparticulelor de argint pentru conservarea artefactelor istorice a fost abordată și mai multe lucrări au raportat utilizarea unor astfel de tratamente pentru conservarea patrimoniului cultural. În această lucrare, proba istorică testată a constat dintr-o țesătură de bumbac, parte dintr-un costum de preot, datând din secolul al XVIII-lea, furnizată de Biserica Sfântul Nicolae „Dintr-o Zi”, situată în București. Piesa a fost tratată cu tratament pe bază de AgNPs, care a fost fito-sintetizat prin utilizarea unui extract apos de plantă. Efectul tratamentului asupra probei a fost examinat prin studierea fibrelor textile cu microscopie electronică (SEM) și prin cuantificarea modificării aspectului probei, folosind măsurători ale parametrilor cromatici. Activitatea antimicrobiană a fost testată împotriva tulpinilor de bacterii gram-pozitive și gram-negative, Escherichia coli și Staphylococcus aureus, și împotriva tulpinii fungice Penicillium hirsutum. Stratul de nanoparticule de argint a fost distribuit uniform pe suprafața fibrelor textile istorice. Modificările în aspectul materialului textil au fost minime, cu o diferență totală de culoare de 2,11. Evaluând activitatea antimicrobiană, s-au observat performanțe antifungice superioare față de tulpina Penicillium hirsutum (pentru care valoarea zonei de inhibiție a fost de 12,5 mm). Spectrul FTIR a demonstrat că integritatea fibrei textile se menține în urma aplicării tratamentului.

Cuvinte-cheie: *nanoparticule de argint, tratament de conservare, textile istoice*

INTRODUCTION

Many studies carried out in applied nanomaterials science have been highlighting the effectiveness of silver nanoparticles (AgNPs) against microbial contamination [1]. In the past decades, these nanomaterials have been tested for various applications, within the textile department, such as smart textiles [2], wound dressings [3], medical textiles [4], textile cultural heritage [5], etc. The papers reporting the antimicrobial effectiveness of AgNPs-based treatments applied on textiles paved the way towards using the AgNPs in conservation science [6]. Since the growth of microorganisms and their metabolic products constitute one of the main causes of fibre degradation, the solution of using an antimicrobial treatment represents a suitable approach [7, 8]. Moreover, the advantage of using such treatments lies in a change of the conservation strategy, by approaching a biocidal effect rather than bacteriostatic, conferred by the conventional methods (appropriate microclimate or treatments designed to create an unfriendly environment for the growth of microorganisms) [9, 10]. Furthermore, when synthesising AgNPs by environment-friendly methods, the costs are reduced, the manipulation of the treatments does not endanger people or animals, and there is no hazardous impact on the environment [11, 12]. The clean manufacturing character of AgNPs represents a crucial benefit, since it does not involve complex procedures, toxic compounds or and does not produce residues [13]. The potential limitation might include the reproducibility, especially scaling up the production of *green* AgNPs, since the phyto-content of plant extracts might differ depending on the conditions in which the plant was cultivated. Many researchers reported the production of *green* AgNPs, exhibiting antimicrobial properties, using extracts of different parts of the plant, leaf [14], seeds [15] flower [16], root [17] fruit [18] etc. Nivedhitha Kabeerdass studied the biomedical and textile applications of AgNPs fabricated by plant-mediated synthesis. The antimicrobial test on cotton fabrics provided values of the inhibition zone in the range 6–10 mm against *E. coli*, *S. aureus*, *P. aeruginosa*, *K. pneumoniae*, *K. oxytoca*, and *A. baumanii*, respectively [19]. Nagah S. Saada and the collaborators studied the effect of *green* AgNPs against the biodegradation of historical parchment [20]. Similarly, Amr Fouda and her group conducted tests regarding the effect of biosynthesised AgNPs applied to a historical book and evaluated their performance against fungal deterioration [21].

In the present research, the performances of a phyto-synthesised AgNPs-based treatment were tested on a historical sample. The morphology of the sample fibres was evaluated using the microscopic technique. Moreover, the appearance of the sample has been rigorously verified by measuring the chromatic parameters before and after applying the AgNPs dispersion. This aspect is of great importance in the field of conservation-restoration [22,23]. The IR spectra were recorded to examine possible changes in the fibre structure.

The antimicrobial tests focused on evaluating the effect against a gram-negative strain (*Escherichia coli*), a gram-positive strain (*Staphylococcus aureus*), and a fungal strain (*Penicillium hirsutum*).

EXPERIMENTAL

Materials and methods

All the regents used were purchased from Merck. The AgNPs dispersion was phyto-synthesised and applied according to the protocol reported in our previous research [24]. The ratio of extract: silver precursor was 1:3 (v/v). The sample used to test the effectiveness of the proposed treatment, based on *green* AgNPs, was collected from a historical artifact, dating back to the 18th century, and was provided by the Church of Saint Nicolae “Dintr-o Zi”, located in Bucharest, founded in 1702, by the wife of ruler Constantin Brâncoveanu. This historical sample, made of cotton, is part of a priestly costume.

The antimicrobial tests were conducted using the bacteria strains *Escherichia coli* ATCC 10536 and *Staphylococcus aureus* ATCC 6538, and the fungal strain *Penicillium hirsutum* ATCC 52323. For the culture media, Casein Soya Bean, TSB Tryptic Soy Broth, NB Nutrient broth, EA Enumeration Agar, Digest Agar, SCDLP Casein Soya Bean Digest, and PDA, Potato-Dextrose-Agar were used.

The antibacterial tests were carried out by the diffusion method in agar medium (inhibition zone method) [25, 26]. The entire surface of the Petri dishes was inoculated with the same volume of sample from each microorganism strain, and textile samples (10 mm diameter) were placed on the surface of the nutrient medium and then incubated at 37°C for 24 hours. The formation of a clear inhibition zone (IZ) indicates the antimicrobial efficiency of the samples. The zone of inhibition is calculated according to the following formula:

$$IZ = \frac{D - d}{2} \quad (1)$$

where *D* is the total diameter of the sample and zone of inhibition (mm), and *d* is the diameter of the sample (mm).

For the antifungal analysis, the culture medium is autoclaved, then poured into Petri dishes. In a test tube with the strain to be tested, add 10 mL of sterile water and scrape, then take 1 ml of the suspension with which the entire surface of the Petri dish is seeded. The evolution/involution of the pathogen culture was followed at 72–96 hours by comparison with the negative control plate.

Characterization techniques

The performance evaluation of the applied treatment was quantified by analysing AgNPs deposits on textile fibres, using scanning electron microscopy (SEM), FTIR spectroscopy, chromatic analysis and by determining the antimicrobial properties.

For performing SEM analysis, the FEI Quanta 200 instrument (ThermoFisher Scientific, Waltham, Massachusetts, USA), equipped with an Everhart-Thornley (ET) detector, was used at an accelerating voltage of 15 kV.

The IR spectra were recorded using an FT-IR-ATR spectroscopy instrument from ThermoFisher, and the spectral range was 4000-400 cm^{-1}.

The Datacolor (D65/10 lamp) instrument (Datacolor, Inc., Lucerne, Switzerland) was used for measuring the chromatic parameters, and they were expressed in the CIE L*a*b* system.

RESULTS AND DISCUSSION

Figure 1 presents the image of the heritage sample before and after treating it with the AgNPs dispersion.

Evaluation of the morphology of heritage textile fibres treated with AgNPs dispersion

The morphology of the sample fibres, before and after applying the treatment, is presented in figure 2. The image shows that silver nanoparticles are uniformly distributed on the surface of the fibres.

Chromatic parameters of the heritage textile treated with AgNPs dispersion

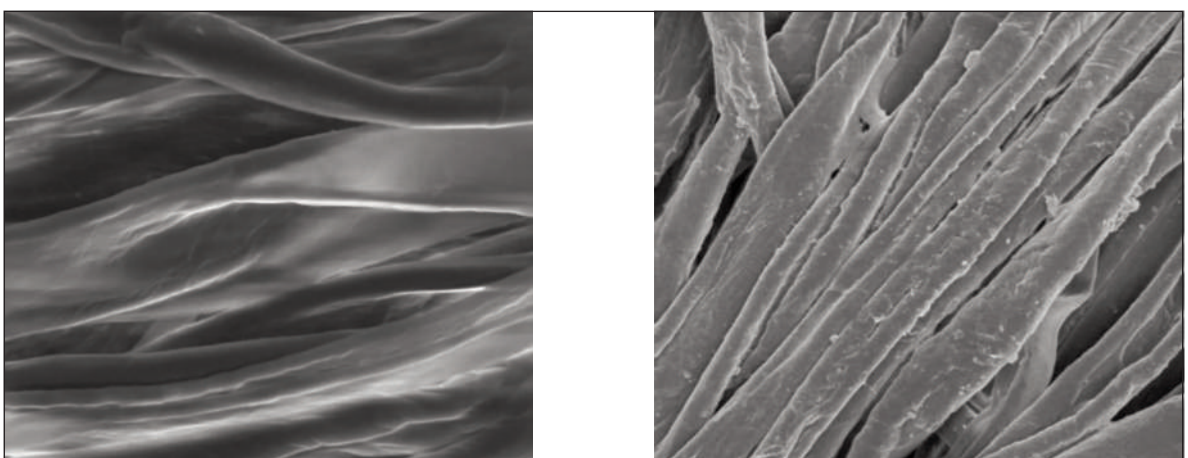
The yellowing of textiles is the most visible indicator of their degradation [27]. In the present case, the historical sample shows shades of yellow, quantified by the value of the parameter b* = 15.50 and a brightness (L*) of 85.52 (table 1). Following the application of AgNPs dispersion, it is noticed that no colour changes occur (figure 3). Moreover, the parameter b* decreased from 15.50 to 14.12.

The colour difference recorded for the textile sample following the application of AgNPs dispersion fulfils the criteria for conservation-restoration of heritage objects [28]. Artefact appearance changes are minimal, and the time patina was maintained following the application of the AgNPs dispersion.

The long term-performance of the AgNPs dispersion is expected to have a minimum effect the appearance of the historical materials, as it resulted from a previous study on the chromatic changes that occurred following the exposure of textiles treated with AgNPs dispersion to conditions of accelerated aging,

a *b*

Fig. 1. Image of the heritage sample: *a* – before; *b* – after treating it with the AgNPs dispersion



a *b*

Fig. 2. SEM images of the historical textile sample: *a* – before; *b* – after applying the AgNPs-based treatment

Table 1

CHROMATIC PARAMETERS OF THE HISTORICAL SAMPLE BEFORE AND AFTER APPLYING THE AGNPS-BASED TREATMENT

Chromatic parameter	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*
Untreated samples	85.52	1.92	15.50	-	-	-	-
Samples treated with AgNPs	84.22	2.85	14.12	–1.30	0.93	–1.38	**2.11**

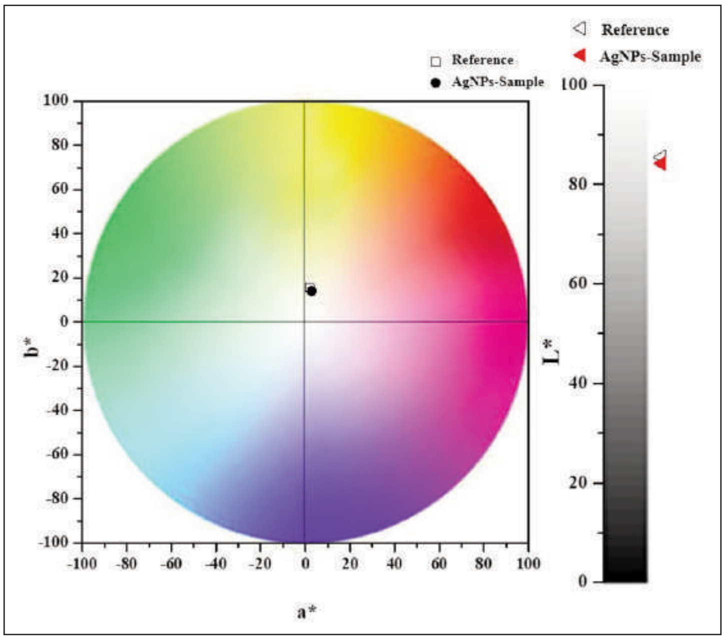


Fig. 3. Chromatic diagram of a historical sample treated with AgNPs dispersion synthesised with *Stellaria media* extract

through a forced degradation process involving UV light, temperature and humidity [29].

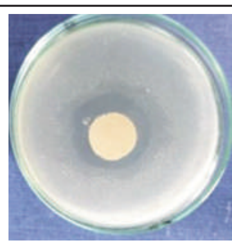
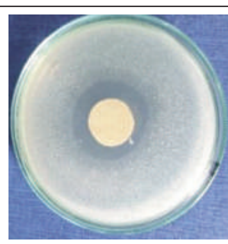
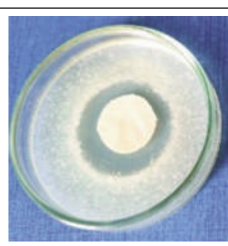
The antimicrobial effect of AgNPs dispersion applied to the heritage textile samples

Antimicrobial tests were performed on the bacterial strains of *Escherichia coli*, *Staphylococcus aureus* and the fungal strain of *Penicillium hirsutum* (table 2). It is observed that the AgNPs dispersion exhibits superior antimicrobial activity against the tested fungal strain. The sensitivity of the pathogen to the antimicrobial action of AgNPs increased in the order *Escherichia coli* < *Staphylococcus aureus* < *Penicillium hirsutum* (figure 4).

The cytotoxic effect of AgNPs on microorganisms could be attributed to the generation of intracellular reactive oxygen species (ROS) in highly reactive bacteria. The interaction of AgNPs with microbial cells often generates ROS radicals, superoxide ($O_2{\bullet}^-$), hydroxyl radical (OH•), and hydrogen peroxide (H_2O_2), which can interact and inactivate various cellular components such as DNA, cell membrane or enzymes, leading to the death of bacteria. Also, another factor favouring the destruction of cells is the zeta potential of Ag nanoparticles, which causes disturbances in the lipid bilayers of the cell membrane, leading to the loss of ions and other components, the formation of pores, as well as the dissipation of the electric charge of the membrane [30]. Although the exact mechanism of action of AgNPs on microbial agents is still unknown, the possible mechanism involves the attachment of nanoparticles to the outer cell membrane and its rupture, followed by penetration into the inner membrane and inactivation of respiratory chain dehydrogenases.

Table 2

IMAGES OF PETRI DISHES INOCULATED WITH THE TESTED MICROBIAL STRAINS AND INCUBATED WITH THE HISTORICAL TEXTILE SAMPLE TREATED WITH THE AGNPS DISPERSION

Microbial strain	AgNPs-treated samples
Escherichia coli	
Staphylococcus aureus	
Penicillium hirsutum	

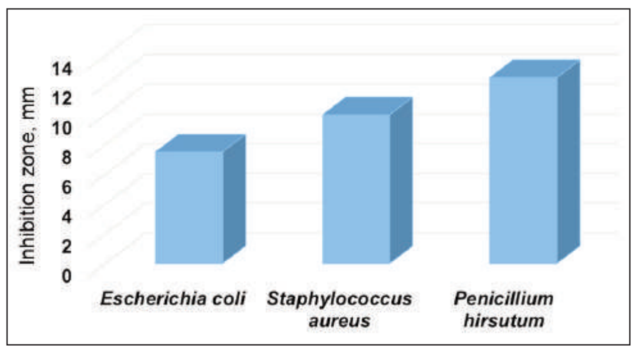


Fig. 4. The zone of inhibition formed on the *Petri dishes inoculated with the tested microbial strains and incubated with the historical textile sample treated with the AgNPs dispersion*

Characterisation by IR absorption spectroscopy of the historical textile sample treated with AgNPs dispersion

The effect of the AgNPs dispersion on the chemical composition of the historical sample was assessed by IR absorption spectroscopy. Figure 5 shows the overlapped FT-IR spectra recorded for the untreated and treated sample, respectively, which represents the fingerprint of the chemical bonds present in the sample. The bands present in the FTIR spectra are characteristic of cotton and are due to the cellulose macromolecule. These bands appear at 3273 cm^{-1},

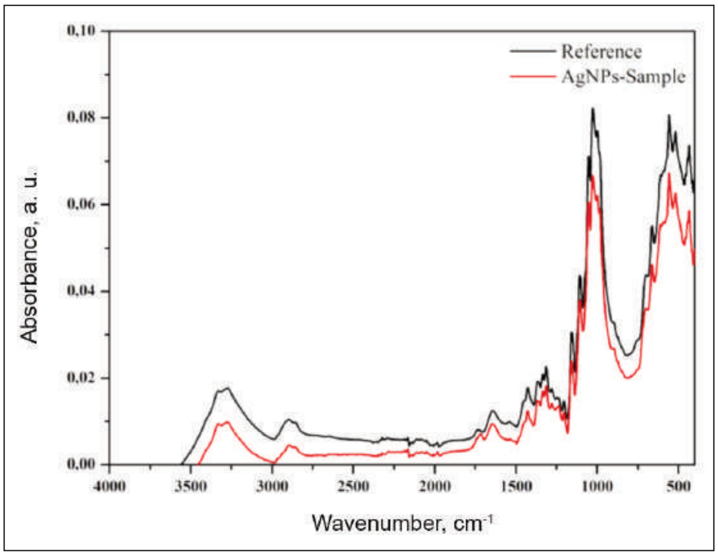


Fig. 5. Absorption IR spectra of the historical textile before and after applying the AgNPs dispersion

attributed to O–H bond stretching energy, 2899 cm^{-1}, corresponding to C–H bond stretching, 1426 cm^{-1}, attributed to C–H bond vibration, 1314 cm^{-1}, bond torsion C–H and 1027 cm^{-1}, C–O bond stretching. Spectra obtained for the sample treated with AgNPs reveal no new bands compared to the control, demonstrating that no chemical reaction occurs on the cellulose during AgNPs coating [31].

CONCLUSIONS

The silver nanoparticles adhered uniformly and abundantly to the textile fibres belonging to the historical sample. After depositing the AgNPs dispersion, changes in the appearance of the textile were minimal, with a total colour difference of 2.11, while maintaining the patina of time. Evaluating the antimicrobial activity, superior antifungal performance was observed against the *Penicillium hirsutum* strain (for which the inhibition zone value was 12.5 mm). The FTIR spectrum demonstrated that the textile fibre is not affected at the chemical composition level, maintaining its integrity following the application of the treatment.

The limitation of such treatments might involve the potential toxicity of AgNPs in mammalian cells. However, given the external use and the formulation of the treatment into dispersions, their manipulation should have no impact on human health. Nevertheless, this study can be further pursued to evaluate the durability of the treatments or the potential resistance that the bacteria might acquire over time. Future experiments aim to study the durability of the produced dispersion in the context of antimicrobial performances, pursuing antimicrobial testing on a wider spectrum of bacterial strains and different types of textile materials.

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Dynamic influence of assembly and cam profile machining errors in the modulator of dobby

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ABSTRACT – REZUMAT

Dynamic influence of assembly and cam profile machining errors in the modulator of dobby

This study delves deeply into the dynamic performance of modular dobby systems used in the textile industry, underscoring the pivotal role of assembly errors in high-speed environments. It uncovers that such errors significantly escalate the vibration of follower components at elevated speeds, with the impact becoming more pronounced as speed increases. Whether employing interference or clearance fits, discrepancies between the cam and roller substantially influence the mechanism's dynamic behaviour. Although interference fits can partially mitigate vibration, they may intensify during high-speed operations. In contrast, clearance fits not only heighten vibration but also reduce contact stiffness, thereby affecting the mechanism's precision and longevity. Drawing from these findings, the study advocates for the preferential use of ideal or interference fits during design and assembly to minimise or eliminate the need for clearance fits. Ideal fits are conducive to maintaining low vibration levels, while interference fits bolster contact stiffness and diminish vibration. Additionally, maintaining optimal lubrication is imperative for curbing friction, wear, and vibration, thereby directly enhancing system performance and stability. In conclusion, a comprehensive grasp of how assembly errors affect modular dobby machines is of paramount theoretical and practical significance, facilitating design optimisation and bolstering the mechanism's performance and reliability.

Keywords: *dobby, modulator, assembly errors, dynamic performance, vibration amplitude*

Influența dinamică a erorilor de asamblare și de prelucrare a profilului camei în modulatorul ratierei

Acest studiu analizează în profunzime performanțele dinamice ale sistemelor modulare cu ratieră utilizate în industria textilă, subliniind rolul esențial al erorilor de asamblare în medii de mare viteză. Studiul scoate la iveală faptul că astfel de erori sporesc semnificativ vibrațiile componentelor tachetului de camă la viteze ridicate, impactul devenind mai pronunțat pe măsură ce viteza crește. Indiferent dacă se utilizează ajustări cu interferență sau cu joc, discrepanțele dintre came și role exercită o influență substanțială asupra comportamentului dinamic al mecanismului. Deși ajustările prin interferență pot atenua parțial vibrațiile, acestea le pot intensifica în timpul funcționării la viteze mari. În schimb, ajustările cu joc nu numai că sporesc vibrațiile, dar reduc și rigiditatea de contact, afectând astfel precizia și longevitatea mecanismului. Pornind de la aceste constatări, studiul pledează pentru utilizarea preferențială a ajustărilor ideale sau de interferență în timpul proiectării și asamblării pentru a minimiza sau elimina necesitatea ajustărilor cu joc. Ajustările ideale sunt favorabile menținerii unor niveluri scăzute de vibrații, în timp ce ajustările cu interferență consolidează rigiditatea contactului și diminuează vibrațiile. În plus, menținerea unei lubrifieri optime este imperativă pentru reducerea frecării, uzurii și vibrațiilor, sporind astfel în mod direct performanța și stabilitatea sistemului. În concluzie, o înțelegere cuprinzătoare a modului în care erorile de asamblare afectează mașinile modulare cu ratiere este de o importanță teoretică și practică capitală, facilitând optimizarea proiectării și sporind performanța și fiabilitatea mecanismului.

Cuvinte-cheie: *ratieră, modulator, erori de asamblare, performanță dinamică, amplitudinea vibrațiilor*

INTRODUCTION

In the field of modern mechanical engineering, system dynamics is a discipline that investigates the behaviour of complex systems, with a focus on constructing accurate mathematical models to simulate and analyse the kinematic and dynamic characteristics of mechanical systems. As technology advances and industrial demands increase, optimising the performance of dobby modulators has become a prominent research area. The modulator in dobby machines transfers motion to the reed frame through linkages, directly impacting the weaving machine's opening performance [1, 2]. Therefore, it is crucial to study the dynamic performance of this mechanism.

Currently, the kinematic and dynamic analysis of the dobby often overlooks the influence of elastic deformation in the components on the motion characteristics of the reed frame [3, 4]. However, as dobby machines move towards lightweight and high-speed development, the inertia force and system flexibility significantly increase, and the effects of component elastic deformation on overall performance become more pronounced. The elastic deformation of key components in the modulator not only affects the dynamic behaviour of the take-up mechanism but also has important implications for the dynamic characteristics of dobby systems due to vibration responses [5, 6]. Therefore, studying the influence of component flexibility deformation on the opening performance of the reed frame in dobby modulators holds great theoretical and practical significance in addressing issues such as low motion stability and poor reliability. In the modulator, assembly errors between the cam and the follower are inevitable and directly impact the mechanism's dynamic response. Analysing the dynamic behaviour of the cam and follower under ideal fit, interference fit, and clearance fit reveals that assembly errors have a significant influence on the follower's vibration amplitude. This influence becomes more prominent, particularly at high speeds, necessitating precise control of assembly accuracy between the cam and follower in engineering applications to reduce clearance errors. Further research demonstrates that as the gear rotation cycle lengthens, the impact of assembly errors between the cam and the follower on the follower's dynamic behaviour in the modulator becomes more significant [7, 8]. In low-speed dobby operation, interference fit reduces follower vibration compared to clearance fit. However, at high speeds, both interference fit and clearance fit result in significant follower vibration. Therefore, during the assembly of the cam and follower, emphasis should be placed on ideal fit and interference fit, while clearance fit should be avoided or minimised, and appropriate lubrication conditions should be ensured. In conclusion, studying component flexibility deformation and its effect on the opening performance of the reed frame in dobby modulators not only provides theoretical support for optimising dobby design but also guides assembly and maintenance work in practical engineering, thereby enhancing overall performance and reliability [9, 10].

DYNAMIC MODEL OF THE FRAME

The schematic diagram in figure 1 depicts the modulator in the dobby. A centralised mass approach was used to construct the dynamic model, simplifying it to two mass elements, three spring elements, and three damper elements. This simplified model enables thorough analysis of dynamic characteristics like vibration, impact, and stability, supporting theoretical and practical evaluation. Ignoring the rolling friction coefficient streamlines the model to focus on essential dynamic factors. Deriving motion differential equations from Newton's second law allows for an accurate description of component motion, aiding in analysing dynamic behaviour, predicting performance, and optimising design, as shown in equation 1. The equation serves as the core of dynamic analysis, offering insights into the mechanism's dynamic response characteristics like vibration frequency, amplitude, and damping ratio during operation, ensuring safe and stable performance.

$$\begin{cases} m_1\ddot{y}_1 = k_1[S(\theta) - y_1] - F(\theta) + b_1[\dot{S}(\theta) - \dot{y}_1] - \\ \qquad - k_2(y_1 - y_2) - b_2(\dot{y}_1 - \dot{y}_2) \\ m_2\ddot{y}_2 = -k_3[y_2 - T(\theta)] + F(\theta) - b_3[\dot{y}_2 - \dot{T}(\theta)] + \\ \qquad + k_2(y_1 - y_2) + b_2(\dot{y}_1 - \dot{y}_2) \end{cases} \quad (1)$$

Several key parameters and variables are pivotal in the dynamic model of the modulator, collectively influencing its dynamic behaviour and performance:

- $S(\theta)$ represents the actual displacement of the main cam, impacting the follower's motion trajectory and velocity.

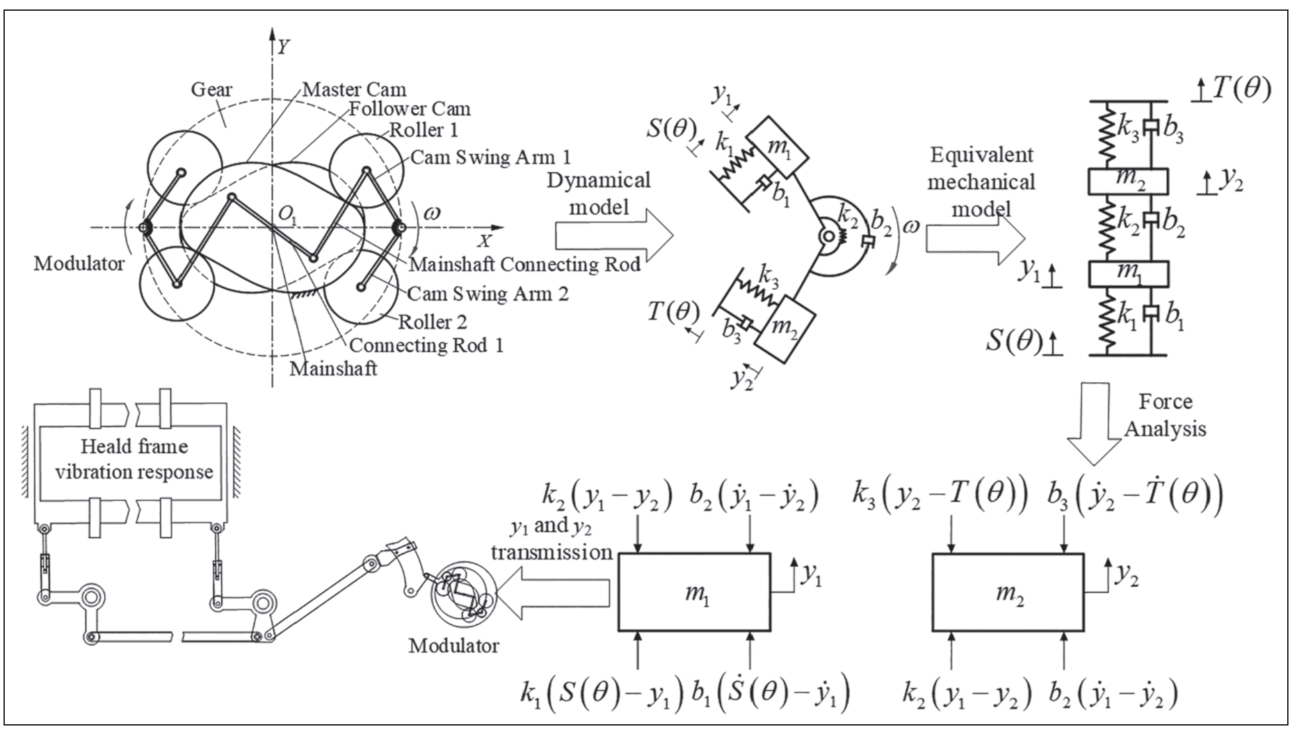

Fig. 1. The schematic diagram of the modulator in the dobby

- $T(\theta)$ represents the displacement coordinates of the secondary cam, influencing the complex motion patterns of the mechanism.
- $F(\theta)$ represents the applied load, directly affecting dynamic response and stability.
- y_1 and y_2 represent the displacements of follower mass blocks m_1 and m_2, reflecting dynamic characteristics.
- k_1, k_2 and k_3 represent the stiffness of the three springs, impacting deformation and vibration.
- b_1, b_2 and b_3 represent the damping coefficients of the three dampers, enhancing stability and reliability by reducing vibration and impacts.

These interconnected parameters and variables form a complex system in the modulator's dynamic model. Precise modelling and analysis of these components provide insights into their working principles, performance prediction under various conditions, and a scientific basis for optimisation design. Additionally, various errors in the modulator should be considered.

$$S(\theta) = S_1(\theta) + \Delta S(\theta) \tag{2}$$

In the equation, $S_1(\theta)$ represents the ideal displacement of the main cam in the modulator, and $\Delta S(\theta)$ represents the displacement variation of the main cam.

Vibration amplitude Δy: more context or information is needed to provide a specific definition or description of the vibration amplitude Δy.

$$\Delta y = y_1 - S_1(\theta) \tag{3}$$

Vibration amplitude F_u refers to the maximum displacement or distance travelled by a vibrating system from its equilibrium position. It represents the extent of oscillation or vibration experienced by the system.

$$F_u = \max \Delta y(\theta_i) - \min \Delta y(\theta_i) \tag{4}$$

where $\theta_i \in \left[36i°, 36(i+1)°\right)$, $i = 0,1,2,\ldots,19$.

The random error of the cam profile is shown in figure 2, and table 1 defines the range and magnitude of the random machining errors that occur.

In the design and analysis of the modulator, the assembly accuracy between the cam and roller has a significant impact on the dynamic performance of the mechanism. Assembly errors, including interference fit and clearance fit, can cause variations in the vibration amplitude of the follower, thereby affecting the stability and efficiency of the entire system.

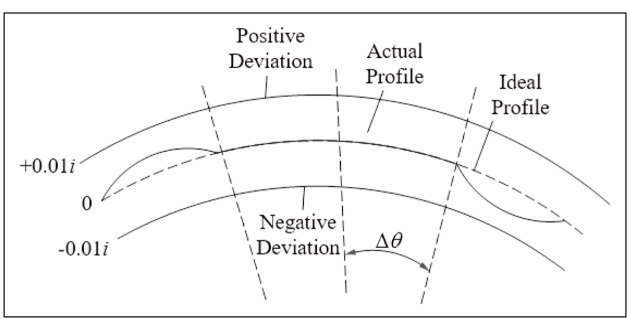

Fig. 2. The random error of the cam profile

Table 1

THE INTERVAL AND SIZE OF RANDOM MACHINING ERRORS		
Serial number	**Margin of error (°)**	**Magnitude of error (mm)**
1	(43.2 – 45]	$0.01 * S_1(\theta)$
2	(45 – 50.4]	$-0.01 * S_1(\theta)$
3	(129.6 – 135]	$0.01 * S_1(\theta)$
4	(135 – 140.4]	$-0.01 * S_1(\theta)$

Firstly, when the cam and roller are in an ideal fit state, where the assembly error is zero ($\Delta S_1(\theta) = 0$), the vibration amplitude of the follower is minimised. This ideal fit state ensures efficient and stable operation of the mechanism. However, in practical production, an ideal fit is often difficult to achieve due to various limitations during manufacturing and assembly processes.

When the cam and roller are assembled with an interference fit, the assembly error is negative ($\Delta S_1(\theta) = -0.01i{*}S_1(\theta)$, $i = 1,4,8,10$), meaning that the roller is excessively pressed into the cam groove, leading to an increase in the vibration amplitude of the follower. Although interference fit can improve contact stiffness and reduce looseness, excessive interference can cause additional friction and stress, thus exacerbating vibration.

Conversely, when a clearance fit is used, the assembly error is positive ($\Delta S_1(\theta) = 0.01i{*}S_1(\theta)$, $i = 1,4,8,10$), indicating that there is a certain gap between the roller and cam. In this case, the vibration amplitude of the follower is maximal. While a clearance fit can reduce assembly difficulties, it can also lead to decreased contact stiffness, increased vibration and impact, and adverse effects on the accuracy and lifespan of the mechanism.

By considering the dynamic model parameters in table 2 and without considering the load, this study investigated the vibration of the follower gear over two operating cycles. Experimental data revealed the variation of the follower's vibration amplitude in a dobby at different speeds, with particular emphasis on the influence of assembly errors. As shown in

Table 2

DYNAMIC PARAMETERS OF MODULATOR		
Parameters	**Value**	**Unit**
m_1	6.0	kg
m_2	2.5	kg
K_1	$2.5{\times}10^7$	N/m
K_2	$3.0{\times}10^8$	N/m
K_3	$2.5{\times}10^7$	N/m
b_1	2.0	N s/m
b_2	3.0	N s/m
b_3	2.0	N s/m
F_0	$1.0{\times}10^3$	N

figure 3, assembly errors ($i = 1,4,8,10$) exhibit a distinct trend in their impact on vibration amplitude. Under low-speed operation and for cam profile errors $i \leq 4$, interference fit assembly significantly reduces the vibration amplitude of the frame compared to the clearance fit assembly. However, as the speed of the dobby increases, especially beyond 800 rpm, both interference fit and clearance fit assembly significantly increase the vibration amplitude of the frame. When the cam profile error $i > 4$, the situation is different. Under low-speed operation, interference fit assembly leads to a higher frame vibration amplitude compared to a clearance fit assembly. When the speed of the dobby exceeds 600 rpm, both assembly methods cause significant frame vibration amplitude. This finding emphasises that as the speed increases, the influence of assembly errors on vibration amplitude intensifies, especially under high-speed operating conditions, requiring stricter assembly accuracy between the cam and roller.

To provide a more intuitive demonstration of the influence of the rotating speed on the vibration of the follower in the dobby, figures 4, 5 and 6 present the calculated results of the follower's vibration at speeds of 300 r/min, 600 r/min, 800 r/min, and 1000 r/min. These data serve as important references for engineers in designing and optimising the modulator, emphasising the significance of accurately controlling the assembly errors between the cam and roller in engineering practice. This is crucial for reducing clearance errors and improving the overall performance of the mechanism.

When studying the dynamic behaviour of the modulator, the influence of assembly errors between the cam and roller becomes more significant as the gear operating cycle lengthens. This continuous impact of assembly errors during prolonged operation highlights their importance in maintaining stability and efficiency.

In general, interference fits result in smaller vibration amplitudes compared to clearance fits. This is mainly due to increased contact stiffness and reduced relative sliding between moving parts, which mitigates vibration. However, there are exceptions, such as when the dobby speed exceeds 800 r/min, where interference fits can increase vibration amplitudes. This could be attributed to excessive friction and stress generated by interference fits under high-speed operation, leading to stronger vibrations.

Based on these findings, we can conclude that both interference fits and clearance fits have a significant impact on the modulator's follower, regardless of speed. Under low-speed conditions, interference fits generate smaller vibrations compared to clearance

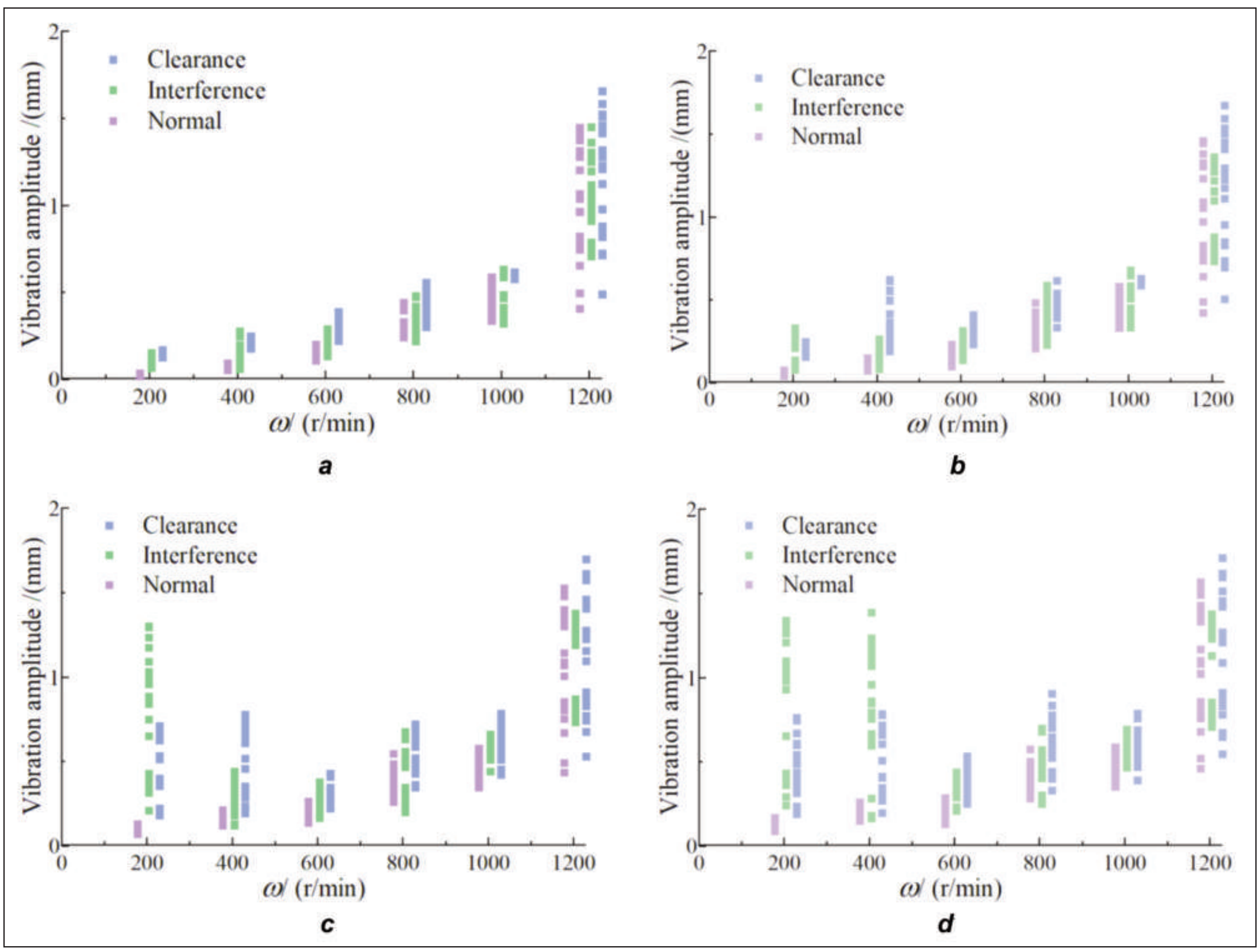

Fig. 3. The vibrational response model of the heald frame:
a – ω = 0.01 rpm; *b* – ω = 0.04 rpm; *c* – ω = 0.08 rpm; *d* – ω = 0.1 rpm

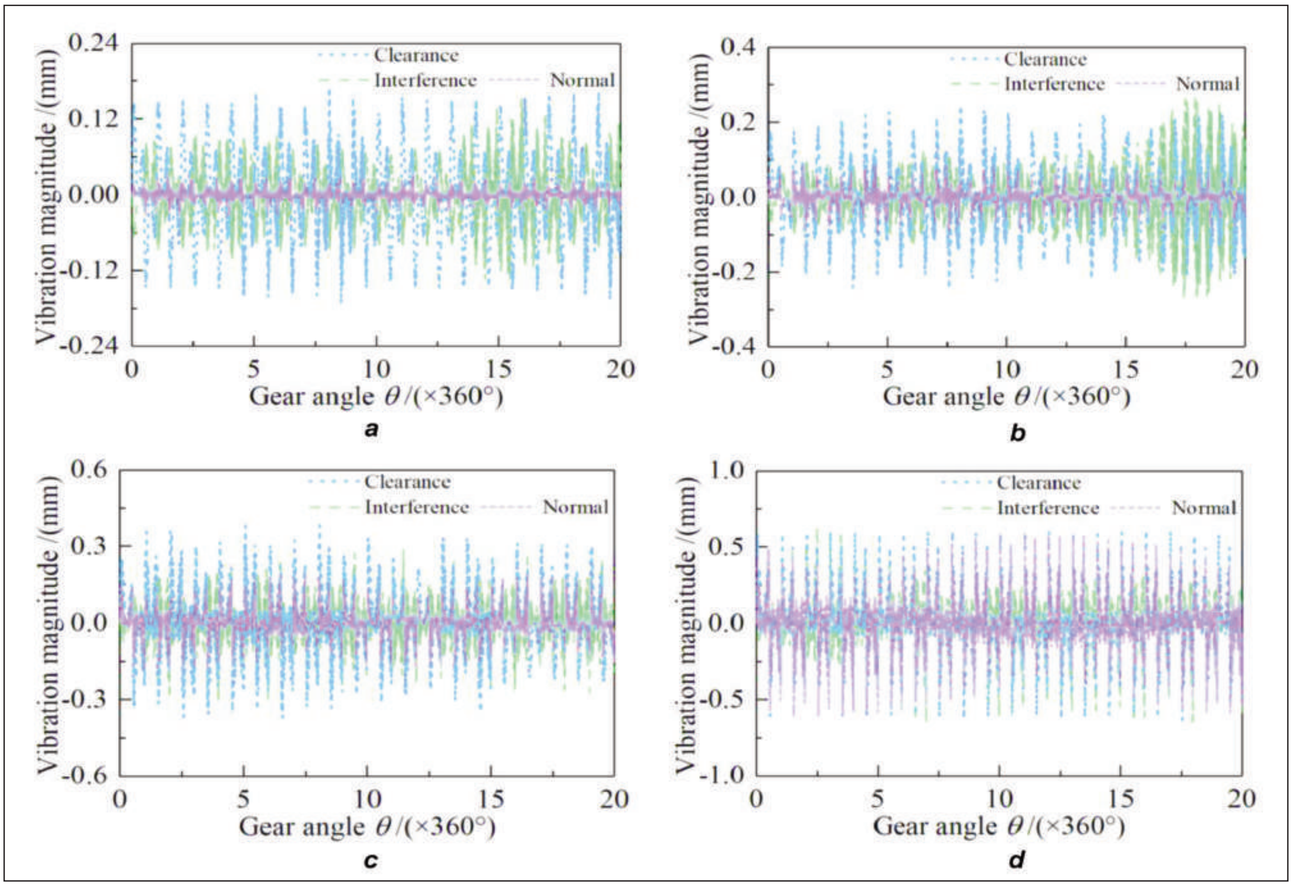

Fig. 4. The vibrational response model of the heald frame 0.01 ($i = 1$):
a – ω = 200 rpm; *b* – ω = 400 rpm; *c* – ω = 600 rpm; *d* – ω = 1000 rpm

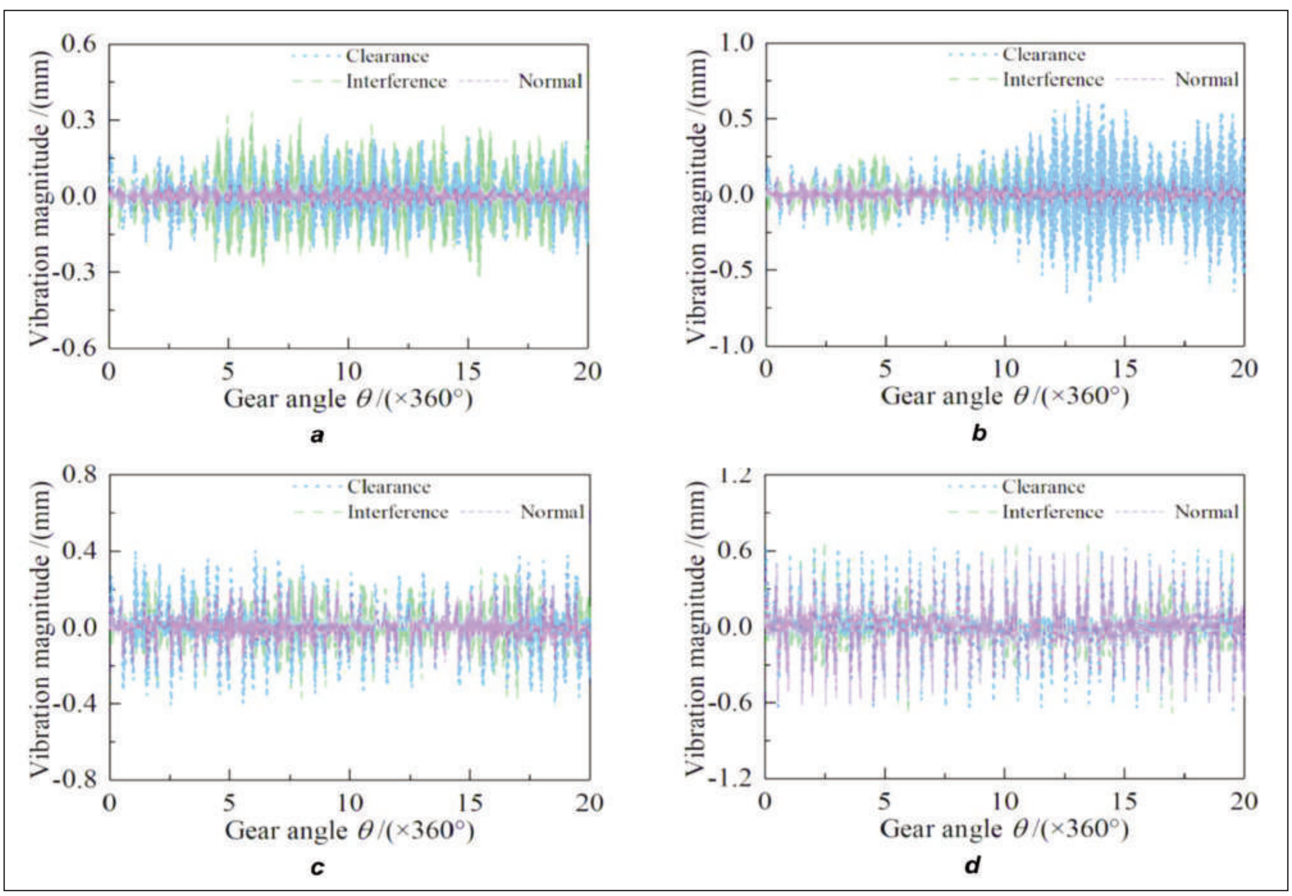

Fig. 5. The Vibrational response model of the heald frame ($i = 4$):
a – ω = 200 rpm; *b* – ω = 400 rpm; *c* – ω = 600 rpm; *d* – ω = 1000 rpm

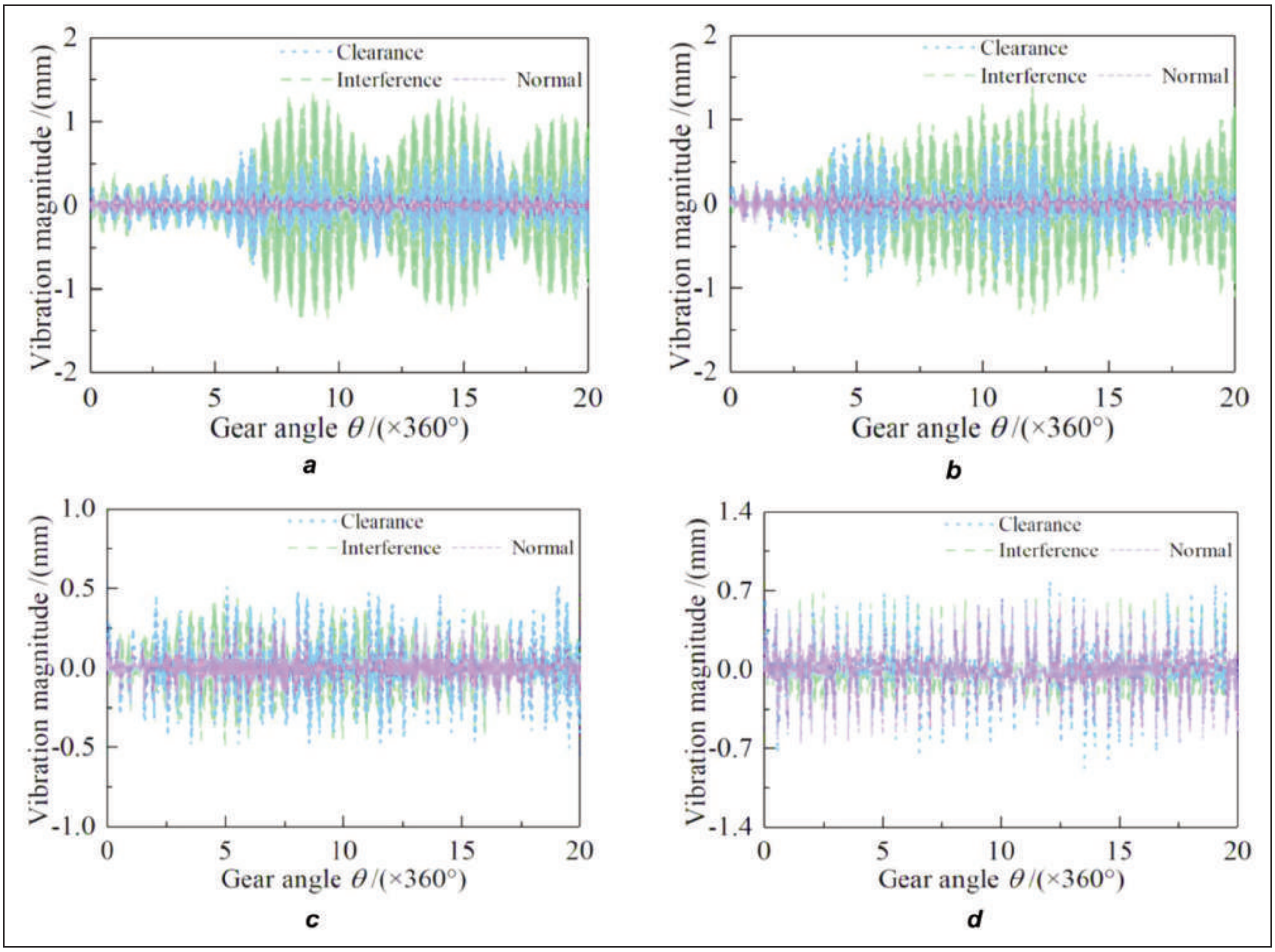

Fig. 6. The Vibrational response model of the heald frame ($i = 10$):
a – ω = 200 rpm; *b* – ω = 400 rpm; *c* – ω = 600 rpm; *d* – ω = 1000 rpm

fits. However, at high speeds, both types of fits can result in larger vibrations, affecting stability and efficiency. To optimise the modulator's performance, it is recommended to choose an ideal fit or an interference fit during the cam and roller assembly, while minimising clearance fits. An ideal fit ensures minimal vibration, while an interference fit increases contact stiffness and reduces vibration. Additionally, maintaining good lubrication conditions is crucial as it reduces friction, minimises wear, and further suppresses vibration, thus improving the overall system's performance and stability.

CONCLUSIONS

The analysis of the dynamic performance of the dobby's modulator reveals the critical influence of assembly errors on system performance. In high-speed operating environments, assembly errors significantly amplify the vibration amplitude of the follower, with this effect becoming more pronounced as the speed increases. Assembly errors between the cam and roller, whether it is an interference fit or a clearance fit, have a significant impact on the dynamic characteristics of the mechanism. While an interference fit helps reduce vibration, it can lead to increased vibration under high-speed conditions. On the other hand, a clearance fit not only increases the vibration amplitude but also decreases contact stiffness, affecting the accuracy and lifespan of the mechanism.

Therefore, when designing and assembling the modulator, it is preferable to use an ideal fit or an interference fit while avoiding or minimising the use of a clearance fit. An ideal fit helps maintain the lowest vibration level, while an interference fit contributes to increased contact stiffness and reduced vibration. Additionally, good lubrication conditions are crucial for reducing friction, wear, and suppressing vibration, directly impacting the improvement of system performance and stability. By optimising assembly fits and lubrication conditions, it is possible to significantly reduce the vibration and wear of the modulator, thereby improving the operational stability and efficiency of the dobby machine. This not only extends the lifespan of the dobby machine but also reduces downtime and maintenance costs, ultimately enhancing overall productivity and economic benefits.

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Application of machine learning methodology for textile defect detection

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ABSTRACT – REZUMAT

Application of machine learning methodology for textile defect detection

This study investigates the use of artificial intelligence (AI) and machine learning (ML) technologies in the textile industry, particularly emphasising how they improve operational efficiency and enhance product quality. Using a comprehensive dataset obtained from textile manufacturing operations, a specially tailored convolutional neural network (CNN) model and a long-short-term memory (LSTM) model are implemented for the classification of fabric defects. After undergoing intensive training and validation, our model showed significant improvements in performance over a large number of epochs. The CNN model started with 61.15% accuracy initially and reached 92.91% accuracy after training. The validation accuracy increased from 72.44% to 92.05%. On the same dataset, the LSTM model resulted in 86.11% training accuracy and 87.80% validation accuracy. The significant improvements in accuracy highlight the power of AI and ML to not only improve classification accuracy but also boost overall operational performance by continuously learning from fresh data inputs. Moreover, this research highlights the impact of AI and ML breakthroughs on textile production as they optimise procedures, enhance efficiency, and strengthen competitive advantage. The findings demonstrate that these technologies are a substantial advancement for the textile sector, providing powerful tools to reduce faults, streamline production processes, and ultimately provide goods of superior quality. Therefore, the study promotes the wider use of AI and ML technologies in the textile manufacturing industry, emphasising their crucial role in driving future advancements and sustainable growth.

Keywords: *artificial intelligence, convolutional neural networks, long short-term memory, machine learning, textile defect detection, textile industry*

Aplicarea metodologiei de învățare automată pentru detectarea defectelor textile

Acest studiu investighează utilizarea inteligenței artificiale (AI) și a tehnologiilor de învățare automată (ML) în industria textilă, cu un accent deosebit pe modul în care acestea îmbunătățesc eficiența operațională și calitatea produselor. Folosind un set cuprinzător de date obținute din operațiunile de producție textilă, un model de rețea neuronală convoluțională (CNN) special adaptat și un model de memorie pe termen scurt și lung (LSTM) sunt implementate pentru clasificarea defectelor materialelor textile. După ce a fost supus unei instruiri și validări intensive, modelul nostru a prezentat îmbunătățiri semnificative ale performanței pe parcursul unui număr mare de epoci. Modelul CNN a început inițial cu o precizie de 61,15% și a atins o precizie de 92,91% după formare. Precizia validării a crescut de la 72,44% la 92,05%. Pe același set de date, modelul LSTM a avut o acuratețe de 86,11% la formare și 87,80% la validare. Îmbunătățirile semnificative ale preciziei evidențiază puterea AI și ML nu numai de a îmbunătăți precizia clasificării, ci și de a stimula performanța operațională generală prin învățarea continuă de la noi date de intrare. În plus, această cercetare evidențiază impactul descoperirilor AI și ML asupra industriei textile, deoarece acestea optimizează procedurile, sporesc eficiența și consolidează avantajul competitiv. Constatările demonstrează că aceste tehnologii reprezintă un progres substanțial pentru sectorul textil, oferind instrumente puternice pentru reducerea defectelor, eficientizarea proceselor de producție și, în cele din urmă, furnizarea de bunuri de calitate superioară. Prin urmare, studiul promovează utilizarea pe scară mai largă a tehnologiilor AI și ML în industria textilă, subliniind rolul lor crucial în promovarea progreselor viitoare și a creșterii durabile.

Cuvinte-cheie*: inteligență artificială, rețele neuronale convoluționale, memorie pe termen scurt, învățare automată, detectarea defectelor textile, industria textilă*

INTRODUCTION

Artificial intelligence (AI) has revolutionised people's lives by enabling the efficient execution of repetitive jobs with enhanced precision [1]. Globalisation has significantly increased people's awareness and understanding of fashion and high-quality apparel. Under these conditions, textile and garment manufacturing companies face a significant demand that they must fulfil [2]. Various machine learning (ML) methodologies have demonstrated their ability to generalise well, not just by enhancing classification accuracy over time but also by acquiring knowledge from novel instances [3]. The advent of AI has revolutionised the way organisations operate and oversee their operations. AI has demonstrated its efficacy in the textile industry by streamlining processes, enhancing productivity, and bolstering competitiveness [4].

Currently, the textile sector extensively utilises electronic equipment equipped with high acquisition rate sensors to gather real-time and uninterrupted data [5].

Researchers have established a connection between the fundamental structural and chemical properties of textile materials [6]. Various traditional mathematical and statistical models have been employed in several textile research projects to analyse textile data [7]. AI has been responsible for driving significant advancements in developing technologies, leading to improvements in several parts of our everyday lives and industries. AI offers solutions to extract valuable insights from large volumes of data generated by industrial processes and online user activities [8]. The quality of an organisation's human resources is dependent on the collection and proficiency of its employees' competencies [9].

Upon reviewing the existing literature, it was observed that ML studies are scarce, specifically focused on detecting defects in textiles. Yildirim et al. [7] offered a comprehensive explanation of the application of data mining techniques, including classification and clustering, and ML algorithms in the textile industry. They aim to showcase the application of these techniques in addressing various problems that traditional methods cannot effectively solve. Shahrabadi et al. [3] provided a concise overview of defect categories and automated optical inspection (AOI), mostly utilising ML approaches. Arora & Majumdar [10] conducted bibliometric, network, and content analyses of research publications in the field of ML and supply chain applications in the textile and clothing industry. Fang et al. [11] created a personalised mobile application (APP) using an internal algorithm to enable simple exchange of health data and provide data-driven cardiovascular diagnostics with only one click.

Kahraman and Durmusoglu [12] aimed to evaluate the use of deep learning for detecting fabric defects. Therefore, they analysed articles that specifically focus on fabric defect detection using deep learning techniques. They conducted a comparative analysis of these works' methodologies, databases, performance rates, comparisons, and architecture types. Guder et al. [13] investigated to assess the efficacy of various deep learning frameworks in accurately categorising fabric faults that are frequently seen in the textile sector in Turkey. A novel data set is created specifically for this purpose, which includes fabric flaws like lines, wrinkle marks, machine oil leaks, holes, and bleaching. Moreover, the efficacy of the Adam and Ranger optimisation functions in detecting defects has been assessed using different models in conjunction with explainable artificial intelligence. The results suggest that the ResNet18+Adam model, despite its simplicity and shallow architecture, achieved a remarkable level of success with an accuracy of 99.30%. In contrast, the more intricate EfficientNetv2m+Adam model demonstrated a remarkable accuracy of 99.42%.

Dlamini et al. [14] implemented a real-time machine vision system for detecting defects in functional textiles. The model was constructed, trained, and evaluated using functional textiles. Their model was implemented on an industrial computer, which received functional textile fabric data from hardware that they specifically created for defect inspection. Their system has attained a precision rate of 95.3%, along with recall and F1 scores of 93.6% and 94.4%, respectively. Jeyaraj and Samuel Nadar [15] focused on designing and developing a computer-aided system for detecting and classifying fabric defects using advanced machine learning algorithms. A complex convolutional neural network is constructed to acquire knowledge from diverse defect data sets during the training phase. During the testing phase, the authors have employed a learning feature to classify defects. The enhancement in the accuracy of defect categorisation has been accomplished by utilising a deep learning method. The researchers evaluated the precision of fault classification on six distinct fabric materials and achieved an average accuracy of 96.55%. This accuracy was determined with a sensitivity of 96.4% and a success rate of 0.94.

Soma and Pooja [16] introduced a novel methodology for identifying faults and defects in the offered fabric samples. Their proposed methodology achieved superior performance with a 95% accuracy rate utilising a neural network and an 85% accuracy rate using SVM. The neural network (NN) classifier is employed to categorise fabrics as either normal or faulty. Ultimately, fault localisation and fabric identification are utilised to determine whether the fabric sample was defective or normal. Liu et al. [17] presented an enhanced version of the YOLOv4 algorithm that achieves superior accuracy in detecting fabric defects. Their improvement involved the use of a novel SPP structure that utilises SoftPool instead of MaxPool. The enhanced YOLOv4 algorithm, equipped with three SoftPools, efficiently handles the feature map, resulting in a notable reduction in the adverse impacts of the SPP structure and a boost in detection accuracy. Huang et al. [18] proposed a highly effective convolutional neural network to accurately identify and localise defects. Their framework's architecture effectively reduces the expense of manually annotating the dataset. It required just a small number of defect samples, along with standard samples, to learn the possible characteristics of defects and accurately identify their locations. Their network is partitioned into two components: segmentation and decision. Their suggested approach required around 50 defect samples to get reliable segmentation findings and can meet the real-time detection requirement at a speed of 25 frames per second (FPS).

In this study, a classification process was performed on the textile defect detection dataset using both convolutional neural networks (CNN) and long short-term memory (LSTM) models. In the Materials and Methods section, datasets and pre-processing steps are detailed. In the classification section, the architecture of the CNN model was created, the training process was analysed, and model performance was evaluated. Similar steps were followed for the LSTM model for comparison. After the completion of the training processes, the performances of both models were compared. In the Discussion section, the results of the models used were compared with four different studies in the literature. Finally, in the Conclusions section, a general evaluation of the study was made, and the obtained findings were discussed comprehensively.

MATERIALS AND METHODS

In this study, the dataset underwent numerous preprocessing stages and model training. The model's performance was assessed using the test dataset, and the results were thoroughly studied. Thus, a highly efficient technique was devised for identifying uncommon irregularities in textile materials. This approach may be regarded as a crucial measure to enhance quality control in textile manufacturing procedures and streamline the identification of faulty items.

Dataset

MVTec provided the dataset used in this study, which was designed to detect unusual abnormalities in textiles. Rare anomalies that occur during textile production can have a significant impact on fabric quality, and detecting them is critical to quality control. This dataset was created for educational purposes and may be used to conduct different anomaly detection research. MVTec is a dataset used for industrial image processing and is widely preferred, especially for anomaly detection. This dataset consists of high-quality images and is suitable for the detection of various industrial defects. The dataset used in our study is optimised for industrial defect detection, similar to MVTec.

The collection comprises photos with pixel sizes of 32x32 and 64x64, as well as several anomaly classifications. These classes include "good", "colour", "cut", "hole", "thread", and "metal contamination". Each picture includes eight possible rotation angles: 0, 20, 40, 60, 80, 100, 120, and 140 degrees. The training and test datasets comprise randomly produced patches, whereas the patches acquired from the source photos do not overlap. This dataset facilitates the conduct of diverse activities across a range of research and application domains. These include class type classification, angle classification, and texture representation learning (also known as self-supervised learning). Class-type categorisation seeks to differentiate several sorts of abnormalities. Angle classification may be used to categorise angles using just "good" photographs while testing images from other classes. Texture representation learning, also known as self-supervised learning, seeks to develop a robust representation of texture rather than typical image processing characteristics. The dataset, in .h5 format, comprises 64×64 pixel patch files classified by error type and randomly sampled. The patches are extracted at various angles, allowing the model to detect abnormalities from several perspectives. This dataset is based on MVTec's publicly accessible dataset. The publication "MVTec AD: A Comprehensive Real-World Dataset for Unsupervised Anomaly Detection" by Paul Bergmann, Michael Fauser, David Sattlegger, and Carsten Steger describes the dataset in full. This study was presented at the 2019 IEEE Conference on Computer Vision and Pattern Recognition (CVPR). Table 1 provides details regarding our data collection, whereas figure 1 displays a representative picture [19, 20].

Table 1

DATASET INFORMATION

Feature	Description
Dataset provider	MVTec company
Purpose of the dataset	Detection of rare anomalies in textile fabrics
Image sizes	32x32 pixels, 64x64 pixels
Classes	good, colour, cut, hole, thread, metal_contamination
Rotations	0, 20, 40, 60, 80, 100, 120, 140
Dataset structure	Training and test datasets contain randomly generated patches. Patches from source images are non-overlapping
File format	.h5 format

Fig. 1. Example image from the dataset

Pre-processing

Data pre-processing is a critical step in improving the accuracy and dependability of machine learning models. This study employs a textile defect dataset made up of 64×64 pixel grayscale pictures with six distinct categories ([‘good’, ‘colour’, ‘cut’, ‘hole’, ‘thread’, ‘metal_contamination’]) and various rotation angles. Initially, training and testing datasets were seeded with random patches selected from non-overlapping source pictures. The initial part entailed preparing the dataset for the binary classification problem. The original dataset had six distinct classifications, but these were reduced to two main categories: “damaged” and “good”. This update makes the dataset easier to manipulate and analyse. TensorFlow completed the class transformation algorithm during this stage. The model’s performance may suffer because of the dataset’s class imbalance. Because the “good” class includes fewer examples, data augmentation techniques were applied to it. Three extra copies were created for each training example, yielding four additional records with “good” category data augmentation. Techniques employed to enhance the data included rotation, cropping, and scaling. These tactics allowed the model to train on a wider range of data, which improved its generalisation skills. The H5ToStorage object was used to process and save the data. This technique reduced the dataset’s memory usage and improved data loading times. The training and test datasets were kept separate and processed by the TensorFlow dataset API. These strategies ensured that the dataset was properly used and sped up the model training process. Several graphs were generated to highlight the effectiveness of the data preparation methods. Figure 2 depicts the distribution of raw data into distinct classifications. This graph demonstrates the dataset’s class imbalances. Initially, the “damaged” class takes up a large portion of the dataset, and this imbalance has the potential to undermine the model’s performance.

Figure 3 depicts the class distribution of a balanced dataset using data augmentation approaches. This graph demonstrates that the “good” and “damaged” classes in the dataset have a more balanced distribution. Data augmentation enabled the model to learn both classes equally well.

Figure 4 depicts samples of training data, demonstrating the diversity and structure of pictures from the “damaged” and “good” classes. These photos show that the dataset is appropriately tagged.

As a result, the data pre-treatment methods in this study include those necessary to eliminate class imbalances and make the dataset TensorFlow compliant. These pre-processing techniques guarantee that the model is trained more evenly and efficiently. Data augmentation and data loading techniques help the model train faster and perform better overall. This improves the ML model’s accuracy and dependability dramatically.

CLASSIFICATION

Convolutional neural networks (CNNs) are models that have been extremely successful in the field of deep learning, particularly in image processing applications. CNNs employ convolutional techniques to extract features from pictures. The initial layers extract simpler and low-level characteristics, whereas the subsequent layers extract more complicated and high-level information. In this approach, the model learns to spot essential patterns in photos. CNN’s fundamental structure includes convolution layers, pooling layers, nonlinear activation functions, and fully connected layers. CNN design starts with convolution layers. These layers use filters to extract various characteristics from the incoming data. Each filter focuses on a certain feature, such as edge detection. For example, in the model employed in this work, the first convolution layer recovers low-level features using three 1×1 filters, whereas the succeeding layers extract more complicated features with bigger filters. In this model, using an L2 regularizer prevents overfitting. After the convolution layers, the pooling layers appear. The pooling technique is utilised to minimise the size of the convolution-derived feature maps as well as the computational burden. For example, Max Pooling determines the maximum value for each depth by traversing with a specific filter size and step interval. This procedure strengthens the model’s translation invariance.

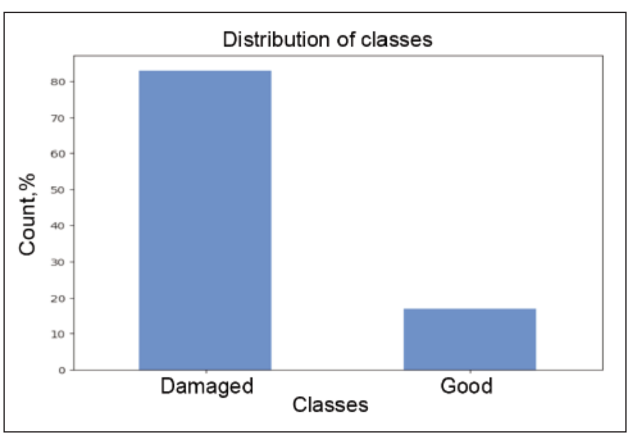

Fig. 2. Initial class distribution

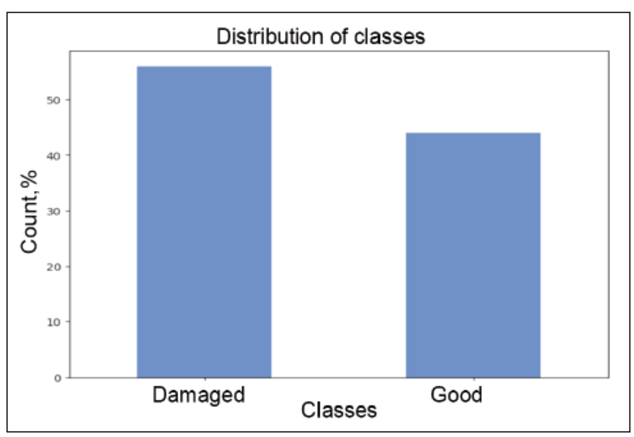

Fig. 3. Balanced class distribution after data augmentation

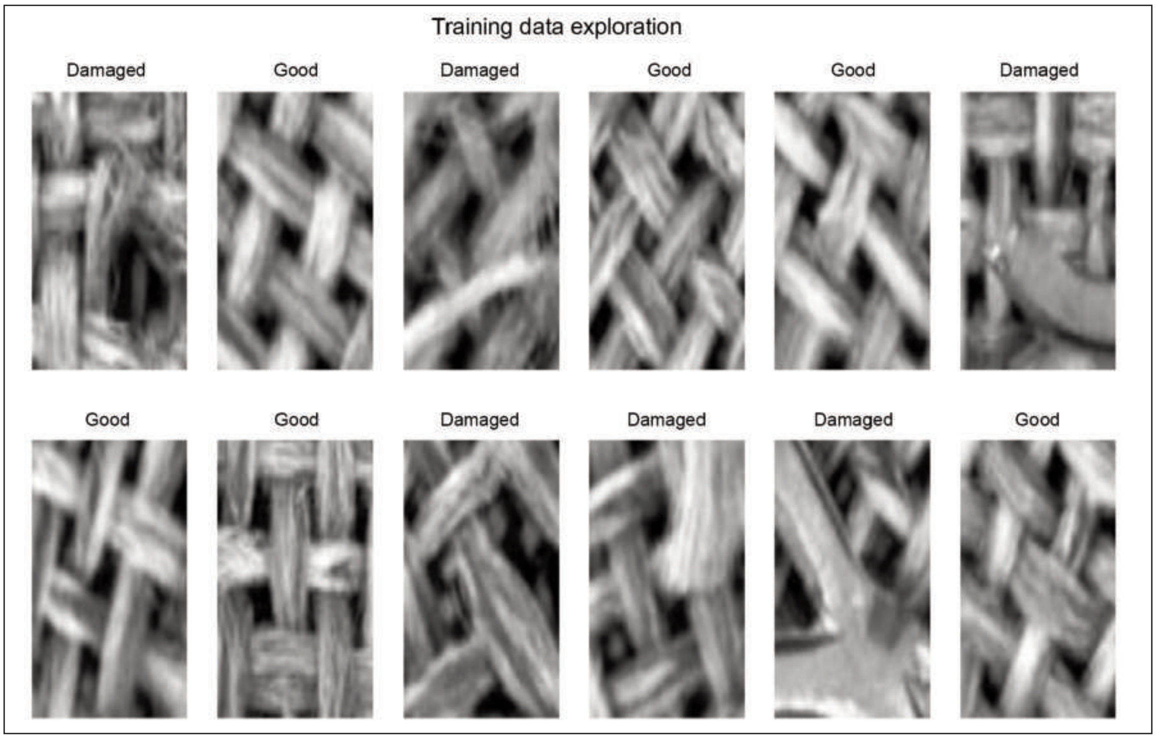

Fig. 4. Training data exploration

Activation functions are critical components that improve the performance of CNNs. This model employs the ReLU (Rectified Linear Unit) activation function. ReLU reduces negative pixel values to zero while keeping positive ones constant. These speed up the network's learning process and increase its effectiveness. The flattening procedure is then followed. The flattening process transforms the final matrix into a vector structure, which artificial neural network models can use as input. This change makes the characteristics extracted from the photos compatible with more typical artificial neural network models. Finally, fully linked layers appear. These layers incorporate the characteristics from the last level of the network and carry out the classification procedure. Fully linked layers enable the model to learn complicated relationships. However, true communication between these layers necessitates the tuning of a huge number of parameters. As a result, strategies like dropout may be employed to minimise the network's overall complexity while also speeding up training. The basic CNN model employed in this work has convolution layers with sizes of 1×1, 2×2, 3×3, 4×4, and 4×4, respectively. The first layer has three filters, while the subsequent levels have 16, 32, 64, 128, and 512 filters, respectively. The model is composed of two pooling layers, both of which use Max Pooling to reduce the size of the feature maps. A single neuron with a sigmoid activation function performs binary classification after the Global Average Pooling Layer reduces the feature maps to a single vector. The purpose of this structure is to efficiently execute tasks such as feature extraction and classification. The model's overall structure and function explain why CNNs perform so well in image processing tasks.

In this study, the CNN model is used as the basis to perform the image classification task. CNNs are considered to be a suitable model for this task, especially because they successfully capture spatial relationships and features in image data. However, to provide a broader perspective by comparing the performance of the CNN model with another model, the LSTM model is also evaluated. Although LSTM is designed to process sequential data and time series data, it is tried as a different approach and applied to the same dataset as the CNN model.

LSTM (long short-term memory) networks are a type of recurrent neural network developed specifically to capture long-term dependencies in sequential data. The main advantage of LSTM is that it can retain previous information in memory for a longer period, thanks to the cell state. The forgetting gates in this structure determine when previous information is preserved and when it is forgotten, and this mechanism strengthens learning by providing access to past information at each step in the sequence. This feature makes LSTM successful in sequential data such as natural language processing and time series analysis. So, LSTM was applied to the image classification task and compared with the CNN model.

The CNN and LSTM evaluation criteria used in this study are dimensionless, meaning that these metrics do not include any physical dimensions or units when measuring model performance. Thus, the results of both models can be compared universally. The inclusion of the LSTM model was performed to provide an alternative perspective and to be able to perform a comparative analysis with CNN. Considering the success of LSTM on sequential data, it was wondered how it would perform on the image classification task. The performance of both models on the dataset was compared, thus providing an additional analysis to establish model preferences on a more solid basis. As a result, the LSTM model was used for comparison and was subjected to performance analysis on the same task as the CNN model.

Applying CNN to the dataset

This study used the MVTec dataset and a CNN to detect unusual abnormalities in textiles. This dataset permits a study into the detection of infrequent abnormalities that play an important role in quality control procedures.

Creating the model architecture

Table 2 details the construction of a TensorFlow sequential model named “baseline_model”. The CNN architecture, a deep learning approach, serves as the foundation for this model. The model has several distinct layers and a complex structure, each serving a specific function. First, the model’s input layer receives single-channel (grayscale) 64×64 pixel pictures. The convolutional layers come next, and they provide the model’s feature extraction capabilities. These layers use convolution to learn various visual properties. Each convolution layer generates a particular number of filters and a certain output size. For example, the first convolution layer applies three 1×1 filters to the 64×64 input pictures to generate a 64×64×3 output. The pooling layers follow the convolution layers. These layers are used to minimise the size of feature maps while also representing the scale and placement of learned features over a larger region. For example, the first pooling layer uses a pooling technique to reduce the 64×64 feature maps to 2×2. The last layer of the model is known as the Fully Connected (Dense) Layer. This layer is used to merge the characteristics from the preceding layers and complete the classification process. In this model, the sigmoid activation function generates the output from a single neuron in the last layer. The total number of parameters indicates the weights and biases that the model may learn during training. There are 1,201,591 parameters in this model. The model can modify all these trainable parameters as it undergoes training. There are no untrainable parameters, which means that the model’s parameters all have fixed structures. Table 2 is a significant tool for assessing the model’s complexity and learning potential.

Compiling and training the CNN Model

During the training process, the model was trained on a dataset consisting of 108,000 images. This dataset consists of images belonging to two classes, ‘damaged’ and ‘good’. After the model training was completed, a test dataset consisting of 72,000 images was used to evaluate the performance of the model. This test dataset also consists of images belonging to two classes.

Figure 5 details the training and performance of a deep learning model. This data depicts the model’s progress during each epoch, as well as the many metrics used to evaluate its success. Large datasets gathered over numerous epochs are routinely used to train deep learning models. Each epoch is a dataset that the model processes only once. During each epoch, the model refines its random parameters at a set learning rate. This method assesses metrics like as model accuracy and loss across both the training and validation datasets. At the beginning of the training phase, the model had low accuracy and a significant loss. This shows that the model hasn’t fully mastered the dataset’s patterns. In the first epoch, the training accuracy was 61.15%, while the training loss was 0.9853. Validation accuracy is 72.44%, with a loss of 0.4640. In succeeding epochs, the model begins to learn patterns from the training dataset, and training accuracy quickly improves as loss reduces. For example, by the third epoch, training accuracy had increased to 88.51% and validation accuracy to 89.89%. Similarly, training loss fell to 0.3207, while validation loss dropped to 0.2657.

Table 2

DETAILS OF THE MODEL ARCHITECTURE

Layer (type)	Output shape	Parameter
conv2d (Conv2D)	(None, 64, 64, 3)	6
conv2d_1 (Conv2D)	(None, 63, 63, 16)	208
conv2d_2 (Conv2D)	(None, 62, 62, 32)	2,080
conv2d_3 (Conv2D)	(None, 60, 60, 64)	18,496
max_pooling2d (MaxPooling2D)	(None, 30, 30, 64)	0
conv2d_4 (Conv2D)	(None, 27, 27, 128)	131,200
max_pooling2d_1 (MaxPooling2D)	(None, 13, 13, 128)	0
conv2d_5 (Conv2D)	(None, 10, 10, 512)	1,049,088
global_average_pooling2d (GlobalAveragePooling2D)	(None, 512)	0
output_layer (Dense)	(None, 1)	513

```
Epoch 1/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1253s 741ms/step - accuracy: 0.6115 - loss: 0.9853 - val_accuracy: 0.7244 - val_loss: 0.4640 - learning_rate: 0.0010
Epoch 2/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1355s 803ms/step - accuracy: 0.7920 - loss: 0.4670 - val_accuracy: 0.8704 - val_loss: 0.3225 - learning_rate: 0.0010
Epoch 3/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1318s 781ms/step - accuracy: 0.8851 - loss: 0.3207 - val_accuracy: 0.8989 - val_loss: 0.2657 - learning_rate: 0.0010
Epoch 4/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1331s 788ms/step - accuracy: 0.8942 - loss: 0.2963 - val_accuracy: 0.9040 - val_loss: 0.2509 - learning_rate: 0.0010
Epoch 5/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1317s 780ms/step - accuracy: 0.8997 - loss: 0.2825 - val_accuracy: 0.9056 - val_loss: 0.2506 - learning_rate: 0.0010
Epoch 6/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1333s 790ms/step - accuracy: 0.9029 - loss: 0.2723 - val_accuracy: 0.9169 - val_loss: 0.2270 - learning_rate: 0.0010
Epoch 7/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1329s 787ms/step - accuracy: 0.9063 - loss: 0.2650 - val_accuracy: 0.9181 - val_loss: 0.2239 - learning_rate: 0.0010
Epoch 8/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 0s 681ms/step - accuracy: 0.9090 - loss: 0.2579
Epoch 8: ReduceLROnPlateau reducing learning rate to 0.00020000000949949026.
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1254s 743ms/step - accuracy: 0.9090 - loss: 0.2579 - val_accuracy: 0.9089 - val_loss: 0.2440 - learning_rate: 0.0010
Epoch 9/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1249s 740ms/step - accuracy: 0.9192 - loss: 0.2362 - val_accuracy: 0.9225 - val_loss: 0.2117 - learning_rate: 2.0000e-04
Epoch 10/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1238s 733ms/step - accuracy: 0.9206 - loss: 0.2311 - val_accuracy: 0.9240 - val_loss: 0.2082 - learning_rate: 2.0000e-04
Epoch 11/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1243s 736ms/step - accuracy: 0.9218 - loss: 0.2279 - val_accuracy: 0.9269 - val_loss: 0.2041 - learning_rate: 2.0000e-04
Epoch 12/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1253s 743ms/step - accuracy: 0.9226 - loss: 0.2254 - val_accuracy: 0.9278 - val_loss: 0.1998 - learning_rate: 2.0000e-04
Epoch 13/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1090s 645ms/step - accuracy: 0.9235 - loss: 0.2233 - val_accuracy: 0.9275 - val_loss: 0.1974 - learning_rate: 2.0000e-04
Epoch 14/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 0s 1s/step - accuracy: 0.9244 - loss: 0.2215
Epoch 14: ReduceLROnPlateau reducing learning rate to 4.0000001899898055e-05.
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 2058s 1s/step - accuracy: 0.9244 - loss: 0.2215 - val_accuracy: 0.9291 - val_loss: 0.1980 - learning_rate: 2.0000e-04
Epoch 15/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 0s 667ms/step - accuracy: 0.9282 - loss: 0.2124
Epoch 15: ReduceLROnPlateau reducing learning rate to 8.000000525498762e-06.
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1234s 731ms/step - accuracy: 0.9282 - loss: 0.2124 - val_accuracy: 0.9084 - val_loss: 0.2384 - learning_rate: 4.0000e-05
Epoch 16/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 0s 688ms/step - accuracy: 0.9291 - loss: 0.2099
Epoch 16: ReduceLROnPlateau reducing learning rate to 1.6000001778593287e-06.
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 1258s 746ms/step - accuracy: 0.9291 - loss: 0.2099 - val_accuracy: 0.9205 - val_loss: 0.2154 - learning_rate: 8.0000e-06
```

Fig. 5. CNN model training process

As the model's performance improves, validation accuracy and loss stabilise or barely change. During this phase, the model frequently lowers its learning rate to allow for more precise adjustments. For example, in the ninth epoch, the learning rate decreased from 0.001 to 0.0002. This update increased validation accuracy and loss. Training accuracy was 90.90%, while validation accuracy was 90.89%. As the training procedure advances, the model's accuracy and loss become more consistent. For example, in the thirteenth epoch, training accuracy grew to 92.35%, validation accuracy increased to 92.75%, and training loss fell to 0.2233 and 0.1974, respectively. The learning rate is gradually reduced to improve the model's performance. In the sixteenth epoch, the learning rate was lowered to 8.0000e-06, which resulted in 92.91% training and 92.05% validation accuracy. As a result, the model was changed to maintain a specific level of accuracy and loss during the training stage. Reducing the learning rate improved the model's performance on the validation dataset without causing overlearning. This approach shows how to train and upgrade deep learning models. These training metrics can be used to evaluate the model's performance and plan future enhancements.

CNN model evaluation

During model training, accuracy and loss values on the training and validation datasets at the end of each epoch must be monitored. Visualising how these variables change over time helps us understand the model's learning and performance. This representation allows us to see how well the model matches training data and performs on new data.

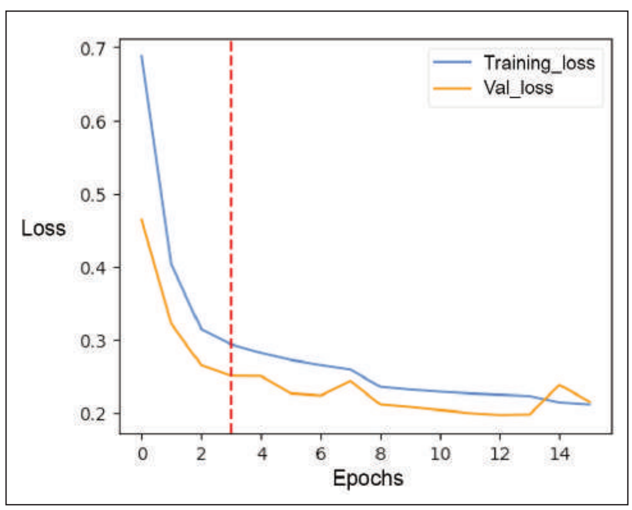

Fig. 6. Training and validation loss of the CNN model

The loss graph in figure 6 depicts the model's error rates in the training and validation datasets on an epoch basis, allowing us to assess the model's learning effectiveness and generalizability. This graph contains two key components: training loss and validation loss. At the start of the graph, the training loss is relatively significant, indicating that the model is having trouble recognising patterns in the dataset. In the first epoch, the training loss is 0.9853. However, as the epochs advance, the model begins to understand patterns in the dataset, and the training loss drops dramatically. This loss decreases dramatically in the second epoch to 0.4670. This demonstrates that the model optimises immediately at the start of the training session and learns patterns rapidly. Validation loss exhibits a similar declining pattern. The validation loss is significant in the first epoch but gradually declines and reaches 0.2657 in the third epoch. This demonstrates that the model not only learns the patterns in the training dataset but also accurately generalises to the patterns in the validation dataset. The red dashed line in the graph represents the point at which the learning rate initially decreased. From this point on, both the training and validation losses become more consistent. Reducing the learning rate allows the model to be tuned in smaller stages, allowing for more precise tweaking. During this phase, the training loss decreases gradually but consistently. In the sixteenth epoch, the training loss fell to 0.2099, while the validation loss fell to 0.2154. Overall, the loss graph indicates that the model finishes the learning process swiftly and effectively. The simultaneous drop in training and validation losses suggests that the model works well on both datasets while avoiding overfitting. This demonstrates that the model improves in a balanced manner on both the training and validation datasets, indicating a successful training procedure.

The accuracy graph in figure 7 displays the model's accuracy rates on the training and validation datasets on an epoch basis, allowing us to assess how effectively the model classifies. The graph has two key components: training accuracy and validation accuracy. The training accuracy was quite poor at the start of the procedure. In the first epoch, the training accuracy was 61.15%. This demonstrates that the model initially struggles to recognise patterns in the dataset, resulting in several false classifications. However, as the epochs advance, the model begins to recognise patterns in the dataset, and training accuracy rapidly

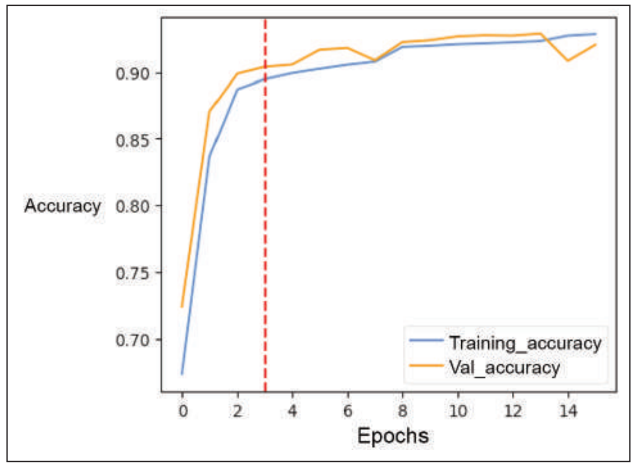

Fig. 7. Training and validation accuracy of the CNN model

improves. A significant improvement in training accuracy is noticed, particularly during the first few epochs. In the third period, training accuracy reaches 88.51%. This demonstrates that the model optimises effectively at the start of the training session and learns patterns rapidly. Validation accuracy examines the model's capacity to generalise. Validation accuracy is likewise poor at the start of the training process, but it improves quickly in tandem with training accuracy. During the first few epochs, validation accuracy improves noticeably. In the third epoch, the validation accuracy was roughly 89.89%. This demonstrates that the model generalises effectively to both the patterns in the validation and training datasets. The graph's red dashed line indicates the initial decrease in the learning rate. From this point on, both the training and validation accuracy are more stable. Reducing the learning rate enables the model to be optimised in smaller stages, allowing for more precise tweaking. Throughout this procedure, training accuracy improves gradually but steadily. In the sixteenth epoch, the training accuracy was 92.91%, and the validation accuracy was 92.05%. Overall, the accuracy graph indicates that the model finished the learning process quickly and effectively. The simultaneous improvement in training and validation accuracy implies that the model performed well on both datasets while avoiding overtraining. This demonstrates that the model improved both accuracy and loss measures in a balanced manner and that the training procedure was effective. These graphs highlight the model's performance and optimisation

Table 3

CLASSIFICATION REPORT				
Parameter	**Precision**	**Recall**	**F1-Score**	**Support**
0	0.98	0.94	0.96	60000
1	0.74	0.88	0.80	12000
accuracy			0.93	72000
macro avg	0.86	0.91	0.88	72000
weighted avg	0.94	0.93	0.93	72000

during the training phase. The parallel trend in training and validation losses and accuracies demonstrates that the model has a high generalisation capacity and minimises overfitting concerns. The model learned the patterns in the dataset rapidly and performed well on both the training and validation datasets. This is a positive measure of the model's overall success and efficiency. Table 3 displays the model's accuracy, precision, recall, and F1 score.

Compiling and training the LSTM model

Figure 8 presents statistical data obtained during the training process of an LSTM model. The training process was monitored for 20 epochs, and the performance of the model on the training and validation sets was evaluated at the end of each epoch. In the first epoch, the training accuracy of the model was 54.51%, while the training loss was recorded as 0.6894. At this stage, the model had not yet learned the patterns in the dataset well enough. However, as the training process progressed, the accuracy of the model increased continuously and reached 86.11% in the 20th epoch. The training loss decreased to 0.3175 in the 20th epoch as the errors of the model gradually decreased. This shows that the optimisation process of the model was successful.

The model's performance on the validation set has also improved similarly. The validation accuracy, which was 54.20% in the first epoch, increased to 87.80% in the 20th epoch. This increase shows that the model can generalise well not only on the training data but also on the validation data. Similarly, the validation loss decreased from 0.6735 in the 1st epoch to 0.2783 in the 20th epoch. This decrease in the validation loss reveals that the model's errors on the validation sets are reduced, and overfitting is avoided. The learning rate dynamics also played an important role in the performance of the model.

The learning rate, which was initially 0.0010, was gradually reduced by the ReduceLROnPlateau algorithm when the validation loss stopped improving. For example, when no significant improvement in validation loss was observed at epoch 9, the learning rate was reduced to 0.0002. This process continued until

```
Epoch 1/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 190s 110ms/step - accuracy: 0.5451 - loss: 0.6894 - val_accuracy: 0.5420 - val_loss: 0.6735 - learning_rate: 0.0010
Epoch 2/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 159s 94ms/step - accuracy: 0.5882 - loss: 0.6641 - val_accuracy: 0.5977 - val_loss: 0.6097 - learning_rate: 0.0010
Epoch 3/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 159s 94ms/step - accuracy: 0.6979 - loss: 0.5669 - val_accuracy: 0.7350 - val_loss: 0.4972 - learning_rate: 0.0010
Epoch 4/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 158s 94ms/step - accuracy: 0.7409 - loss: 0.5130 - val_accuracy: 0.7493 - val_loss: 0.4787 - learning_rate: 0.0010
Epoch 5/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 162s 96ms/step - accuracy: 0.7625 - loss: 0.4835 - val_accuracy: 0.8035 - val_loss: 0.4070 - learning_rate: 0.0010
Epoch 6/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 161s 95ms/step - accuracy: 0.7851 - loss: 0.4534 - val_accuracy: 0.8062 - val_loss: 0.3987 - learning_rate: 0.0010
Epoch 7/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 165s 98ms/step - accuracy: 0.7974 - loss: 0.4318 - val_accuracy: 0.8161 - val_loss: 0.3871 - learning_rate: 0.0010
Epoch 8/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 166s 98ms/step - accuracy: 0.8067 - loss: 0.4149 - val_accuracy: 0.8389 - val_loss: 0.3417 - learning_rate: 0.0010
Epoch 9/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 0s 89ms/step - accuracy: 0.8210 - loss: 0.3921
Epoch 9: ReduceLROnPlateau reducing learning rate to 0.00020000000949949026.
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 170s 101ms/step - accuracy: 0.8210 - loss: 0.3921 - val_accuracy: 0.8175 - val_loss: 0.3864 - learning_rate: 0.0010
Epoch 10/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 166s 99ms/step - accuracy: 0.8371 - loss: 0.3656 - val_accuracy: 0.8621 - val_loss: 0.3097 - learning_rate: 2.0000e-04
Epoch 11/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 162s 96ms/step - accuracy: 0.8465 - loss: 0.3477 - val_accuracy: 0.8637 - val_loss: 0.3070 - learning_rate: 2.0000e-04
Epoch 12/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 165s 98ms/step - accuracy: 0.8490 - loss: 0.3421 - val_accuracy: 0.8680 - val_loss: 0.2879 - learning_rate: 2.0000e-04
Epoch 13/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 170s 101ms/step - accuracy: 0.8502 - loss: 0.3384 - val_accuracy: 0.8729 - val_loss: 0.2862 - learning_rate: 2.0000e-04
Epoch 14/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 0s 89ms/step - accuracy: 0.8568 - loss: 0.3328
Epoch 14: ReduceLROnPlateau reducing learning rate to 4.0000001899898055e-05.
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 170s 100ms/step - accuracy: 0.8568 - loss: 0.3328 - val_accuracy: 0.8725 - val_loss: 0.2902 - learning_rate: 2.0000e-04
Epoch 15/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 175s 104ms/step - accuracy: 0.8581 - loss: 0.3250 - val_accuracy: 0.8777 - val_loss: 0.2790 - learning_rate: 4.0000e-05
Epoch 16/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 0s 92ms/step - accuracy: 0.8610 - loss: 0.3220
Epoch 16: ReduceLROnPlateau reducing learning rate to 8.000000525498762e-06.
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 175s 104ms/step - accuracy: 0.8610 - loss: 0.3220 - val_accuracy: 0.8656 - val_loss: 0.2982 - learning_rate: 4.0000e-05
Epoch 17/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 177s 105ms/step - accuracy: 0.8618 - loss: 0.3209 - val_accuracy: 0.8792 - val_loss: 0.2757 - learning_rate: 8.0000e-06
Epoch 18/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 0s 93ms/step - accuracy: 0.8634 - loss: 0.3177
Epoch 18: ReduceLROnPlateau reducing learning rate to 1.6000001778593287e-06.
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 178s 105ms/step - accuracy: 0.8634 - loss: 0.3177 - val_accuracy: 0.8698 - val_loss: 0.2927 - learning_rate: 8.0000e-06
Epoch 19/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 0s 93ms/step - accuracy: 0.8608 - loss: 0.3198
Epoch 19: ReduceLROnPlateau reducing learning rate to 3.200000264769187e-07.
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 178s 106ms/step - accuracy: 0.8608 - loss: 0.3198 - val_accuracy: 0.8712 - val_loss: 0.2902 - learning_rate: 1.6000e-06
Epoch 20/20
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 0s 94ms/step - accuracy: 0.8611 - loss: 0.3175
Epoch 20: ReduceLROnPlateau reducing learning rate to 1e-07.
1688/1688 ━━━━━━━━━━━━━━━━━━━━ 180s 107ms/step - accuracy: 0.8611 - loss: 0.3175 - val_accuracy: 0.8780 - val_loss: 0.2783 - learning_rate: 3.2000e-07
```

Fig. 8. LSTM model training process

the learning rate dropped to a low level of 3.2000e-07 across epochs. This reduction in the learning rate allowed the model to reach a better minimum with smaller steps and improved the optimisation process. As a result, the LSTM model successfully learned the patterns in the dataset with the statistical performance it showed throughout the training process and was able to generalise this information to the validation set. The high validation accuracy and low validation loss obtained show that the model works effectively and has a good generalisation ability.

LSTM model evaluation

This graph shows the loss values recorded on both the training (training_loss) and validation (val_loss) sets during the training process of the LSTM model. The X-axis represents the epochs, and the Y-axis represents the loss values. The graph shows in detail how the model performs over time and how it progresses in the learning process.

At the beginning of the graph, both the training loss (blue line) and the validation loss (orange line) are at a high level. This shows that the model has not yet fully learned the patterns in the data in the early stages of training. However, after a few epochs, both loss values start to decrease rapidly. This decrease shows that the model starts to perform better on the dataset and that the training process is effective.

The validation loss initially follows a course close to the training loss, and both tend to decrease during this process. This decrease in the validation loss shows that the model's ability to learn not only from the training data but also from the validation data increases. As the epochs progress, both loss values become stable. This indicates that the model has now largely learned the patterns in the dataset. There is limited room for further improvement.

Another striking point in the graph is that the validation loss stabilises at a level very close to the training loss after a certain epoch. This indicates that the generalisation capacity of the model is high. That is, its ability to adapt to new data is strong. The fact that the training loss is slightly lower than the validation loss indicates that the model is slightly more adapted to the training set (fitting), but since this difference is quite small, it cannot be considered as a sign of overfitting.

In general, figure 9 shows graph shows that the model successfully reduces its losses throughout the training process, performs well on the validation set, and eventually both the training and validation losses stabilise at low levels. These results reveal that the model's learning process is effectively managed, and the result obtained is satisfactory in terms of generalisation.

The graph obtained in figure 10 shows that the accuracy and validation accuracy metrics have successfully increased during the training process of the model. When the graph is examined, it is observed that both the training accuracy and validation accuracy have increased rapidly. This increase reveals that

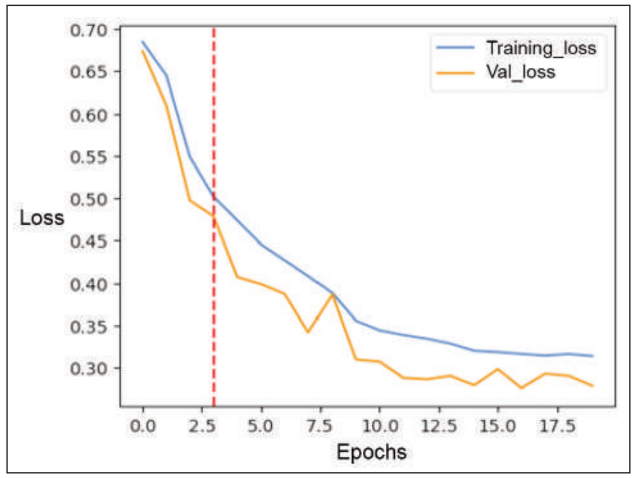

Fig. 9. Training and validation loss of the LSTM model

the model has the capacity to effectively learn the patterns and relationships in the dataset.

Throughout the training process, the steady increase in training accuracy indicates that the model is increasingly grasping the information in the dataset and is continuously improving its performance. Similarly, the increase in validation accuracy parallel to the training accuracy indicates that the model exhibits a successful generalisation ability on new and unseen data. This indicates that the model performs well not only on the training data but also on the validation data.

The accuracy curves observed in the graph reveal that the model has a high learning capacity and maintains its overall performance consistently by maintaining its validation accuracy throughout the training period. These results show that the model performs successfully on both the training and validation sets and has a strong generalisation ability. It can be concluded that the model effectively learns from the dataset by increasing its accuracy over the specified number of epochs and can exhibit robust performance against new data.

As a result, the high accuracy values obtained throughout the training process of the model indicate

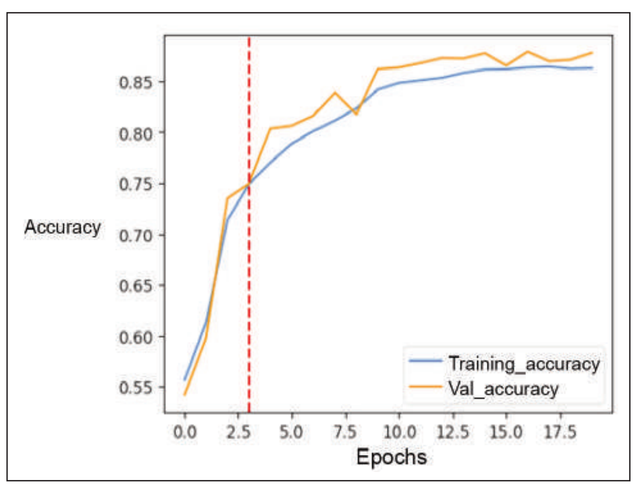

Fig. 10. Training and validation accuracy of the LSTM model

that the model successfully improves its learning ability on the training data and its generalisation capacity on the validation data. These findings demonstrate that the overall performance of the model improves continuously throughout the training period and exhibits strong generalisation ability on the validation data.

Table 4 summarises the classification performance of the LSTM model. The model achieved 87% overall accuracy, exhibiting high accuracy (99% precision, 92% F1-score) in class 0 and strong recall (95%) in class 1. Weighted average metrics reveal that the model demonstrates a successful generalisation ability on the dataset.

Table 5 presents the performance evaluations of the Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) models applied to the dataset. Performance evaluations were made according to the training accuracy, training loss, validation accuracy, and validation loss criteria.

The accuracy rate of the CNN model in the training phase was determined as 92.91%, and the training loss remained at a low level of 0.2099. These results show that the CNN model processed the training data with a high accuracy rate and that the model had a low error margin during the learning process. In the validation phase, CNN also performed quite successfully with an accuracy rate of 92.05% and a loss value of 0.2154. These findings reveal that CNN provided superior overall performance in both the training and validation processes and that the model effectively learned the general features of the data.

In comparison, the training accuracy of the LSTM model was recorded as 86.11%, and the training loss reached a higher value of 0.3175. This result shows that LSTM offers lower learning accuracy and a higher error rate on the training data. In the validation phase, LSTM achieved an 87.80% accuracy rate and 0.2783 loss value. Although LSTM provided slightly higher accuracy in the validation phase, it generally fell behind the performance provided by CNN, considering the limitations in training performance.

When evaluated in general, it reveals that the CNN model provides a significant superiority over LSTM on the dataset. CNN's high training accuracy and low training loss show that the model grasps the characteristics of the data better and is more effective in the learning process. The high accuracy rate in the validation phase also emphasises that the CNN model's generalisation ability is stronger than LSTM. As a result, it has been scientifically clearly demonstrated that CNN provides better results and, therefore, is considered a more effective model in solving the textile defect detection problem.

ALGORITHM TIME PERFORMANCE AND ANALYSIS

The results obtained for the CNN (convolutional neural network) model show that the data was processed quickly and effectively during the training of the model. 72,000 data samples were processed in approximately 14 seconds, and each step of the model was completed in an average of 163 milliseconds. This situation reveals that the CNN model has strong parallel processing ability and can process complex data effectively. This model provides a great advantage, especially when working with high-dimensional and large data sets, such as the analysis of visual data. CNNs are superior in capturing spatial features in the data and are extremely competent in recognising local contexts and patterns.

The results obtained for the LSTM (Long Short-Term Memory) model reveal the model's capacity to process temporal data. The same data set was processed by the LSTM in 13 seconds, and each step was completed in an average of 37 milliseconds. LSTMs are known to exhibit strong performance, especially on time series and sequential data. However, although each step is longer, the data processing speed of the LSTM model is generally higher than the CNN. This is because LSTM learns

Table 4

CLASSIFICATION REPORT				
Parameter	**Precision**	**Recall**	**F1-Score**	**Support**
0	0.99	0.86	0.92	60000
1	0.57	0.95	0.71	12000
accuracy			0.87	72000
macro avg	0.78	0.90	0.82	72000
weighted avg	0.92	0.87	0.89	72000

Table 5

PERFORMANCE COMPARISON OF BOTH MODELS				
Model	**Training accuracy (%)**	**Training loss**	**Validation accuracy (%)**	**Validation loss**
CNN	92.91	0.2099	92.05	0.2154
LSTM	86.11	0.3175	87.80	0.2783

temporal dependencies faster and is better at modelling these dependencies.

When comparing CNN with LSTM models, it becomes clear that while LSTM is best suited for sequential and temporal data sets, CNN has a significant edge over larger and more complicated structures. In particular, CNN models outperform LSTM in fields like computer vision and visual data analysis because of their capability for parallel processing and ability to grasp spatial correlations of data. LSTM, on the other hand, stands out as a more effective model in cases where time series data and sequential dependencies are important. Therefore, when choosing a model, it should be taken into account that the CNN model may be more suitable than the LSTM model, considering the visual structure of the dataset and the characteristics of the problem to be solved. CNN models are generally a preferred approach in our dataset, as they show high performance, especially in visual datasets. Table 6 presents the performance comparison of the Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) models applied to the dataset.

Table 6

PERFORMANCE COMPARISON OF BOTH MODELS

Model	Solution time for the performances (%)	Each step
CNN	14 seconds	163 milliseconds
LSTM	13 seconds	37 milliseconds

DISCUSSION

In this section, a comparative analysis of four related studies is presented. Table 7 summarises the key comparisons between these studies to provide a clearer understanding of their findings and methodologies. Guder et al. [13] focused on the detection of frequently encountered defects in the textile sector in Turkey and used a new dataset specially created for this purpose. In their study, the performance of models such as ResNet18+Adam and EfficientNetv2m+Adam was compared. While the ResNet18 model achieved a high accuracy rate of 99.30% despite its simple and superficial structure, the EfficientNetv2m model, which has a more complex structure, provided a slight superiority with an accuracy rate of 99.42%. Their study is remarkable in terms of showing how effective optimisation functions and deep learning models are in detecting textile defects.

Dlamini et al. [14] developed a real-time machine vision system to detect functional textile defects. This system is integrated on an industrial computer and collects and processes functional textile data with specially designed hardware. The results show that the system is quite successful in industrial applications with a 95.3% accuracy rate, 93.6% recall, and 94.4% F1 score. Their study provides an example that highlights the performance and practical use of deep learning systems in real-time applications.

In the study conducted by Jeyaraj and Samuel Nadar [15], a complex CNN model based on deep learning was used to detect and classify various fabric defects. The study achieved an average accuracy of 96.55% and a sensitivity of 96.4% on 6 different fabric types. The highlight of this study is that deep learning methods can successfully categorise defects using learning features in the defect classification process. These results show that advanced artificial intelligence models such as CNN have great potential for the textile industry. Soma & Pooja [16] presented a new method to detect defects in textile samples using artificial neural networks (NN) and support vector machines (SVM). While the NN model showed higher performance with a 95% accuracy rate, the SVM model reached an 85% accuracy rate. Their study developed an effective method to determine whether textile samples are defective or not, especially by providing localisation and classification of defects.

As a result, these studies show that deep learning and machine learning algorithms provide quite successful results in the detection and classification of textile defects. While Guder et al. [13] and Jeyaraj and Samuel Nadar [15] stand out with their high accuracy rates, Dlamini et al. [14] make a significant contribution in terms of usability in real-time applications.

Table 7

COMPARATIVE ANALYSIS

Authors	Dataset	Methods used	Success rate	References
Guder et al.	Fabric defects (lines, wrinkles, oil leaks, holes)	ResNet18+Adam, EfficientNetv2m+Adam	ResNet18: 99.30%, EfficientNetv2 m: 99.42%	[13]
Dlamini et al.	Real-time data from functional textiles	Real-time machine vision system	95.3% (Precision), 93.6% (Recall), 94.4% (F1)	[14]
Jeyaraj and Samuel Nadar	6 different fabrics materials	Deep learning based CNN	96.55%	[15]
Soma and Pooja	Textile samples	Neural network (NN) ve SVM	NN: 95% SVM: 85%	[16]

Soma and Pooja [16] offer a more general perspective by comparing the performance of different models. These studies reveal that deep learning is an effective solution in quality control processes in the textile industry. Similarly, in this study conducted on the textile defect detection dataset, the performance of CNN and LSTM models also revealed significant findings. The CNN model exhibited high performance, with a 92.91% accuracy rate in the training phase and a 92.05% accuracy rate in the validation phase. This result is similar to the high accuracy rates in the studies of Guder et al. [13] and Jeyaraj and Samuel Nadar [15]. The LSTM model achieved an 86.11% accuracy rate in the training phase and an 87.80% accuracy rate in the validation phase. These results show that although LSTM provides high accuracy in some cases, the CNN model generally performs better.

Comparing the studies in the literature with our results, it is seen that the CNN model is generally more effective in detecting textile defects. This supports the wide application potential of CNN in the field of deep learning, while the LSTM model can also be useful in certain scenarios. These findings emphasise that deep learning methods offer powerful and effective solutions in quality control processes in the textile industry.

CONCLUSIONS

This study investigated the application of artificial intelligence (AI) and machine learning (ML) models – specifically, convolutional neural networks (CNN) and long short-term memory (LSTM) networks – in the detection of textile defects. The primary objective was to evaluate the performance of these models in identifying anomalies in textile images, thereby contributing to enhanced quality control processes in the textile manufacturing industry. The results demonstrated that these advanced technologies hold significant potential in automating defect detection, optimising production processes, and improving the overall efficiency and accuracy of textile manufacturing.

From a general perspective, AI and ML technologies have increasingly become integral tools in the textile sector, where precision and operational efficiency are critical to maintaining high-quality standards. By leveraging these technologies, manufacturers can streamline processes, reduce human error, and increase productivity while maintaining consistent product quality. The automation of defect detection through machine learning models also offers the potential to reduce labour costs and mitigate the risks associated with manual inspection, which can be prone to oversight and fatigue.

The CNN model used in this study exhibited exceptional performance, achieving a training accuracy of 92.91% and a validation accuracy of 92.05%. This model's architecture allowed it to effectively capture spatial relationships and intricate features within the textile images, making it highly suitable for the defect detection task. In comparison, the LSTM model, which is traditionally designed for sequential data and time series tasks, was also applied to the same textile defect detection problem. While LSTM networks are typically known for their capacity to retain information across long sequences, they did not perform as well as the CNN model on this particular image-based dataset. The LSTM model achieved a training accuracy of 86.11% and a validation accuracy of 87.80%, which, while respectable, was still inferior to the CNN model's performance. This outcome highlights the inherent limitations of LSTM when applied to spatial data like images, where CNNs excel due to their convolutional layers' ability to detect and learn spatial hierarchies.

The comparison of the two models provides significant insights into their applicability in different contexts within the textile industry. CNN models, with their strong performance on image-based tasks, are better suited for tasks such as visual quality control, where detecting specific patterns, textures, or irregularities is paramount. On the other hand, LSTM models may still hold value in scenarios where sequential data is involved, such as monitoring time-based production data or tracking real-time changes in textile characteristics.

Moving from the general conclusions to the specific implications of this research, it becomes evident that the integration of AI and ML in textile manufacturing is not merely a theoretical advancement but a practical solution with tangible benefits. The CNN model's ability to detect defects with high accuracy indicates that machine learning can be directly applied to industrial production lines, leading to real-time defect detection and correction. This can significantly enhance quality control processes by identifying defects at early stages of production, reducing waste, and ensuring that only high-quality products reach the market. Furthermore, the implementation of AI-driven systems in the textile industry can support predictive maintenance, allowing manufacturers to anticipate and address equipment failures before they cause defects. This proactive approach to maintenance can further optimise production efficiency and reduce downtime, contributing to cost savings and increased profitability. In addition to quality control, the use of AI and ML in the textile sector can enable more flexible and responsive manufacturing processes. With the increasing demand for customisation and fast fashion, AI models can be used to adapt production lines to meet specific customer requirements more quickly and accurately. This capacity to deliver personalised products while maintaining high standards of quality gives manufacturers a competitive edge in the global market.

The limitations of this study should also be acknowledged. While the CNN model performed admirably in detecting textile defects, the dataset used in this research may not fully represent the diverse range of defects encountered in real-world manufacturing settings. Future work could involve training and testing the model on larger and more varied datasets to enhance its robustness and applicability across different textile types and production environments.

The integration of AI and ML technologies into the textile industry in the future will not only enhance current processes but also represent a transformative transition toward more intelligent, adaptive, and efficient manufacturing systems. Defect identification, predictive analytics, and manufacturing optimisation should all show considerably more progress as artificial intelligence develops. The use of AI in green manufacturing practices, reducing waste and improving resource efficiency, is another area ripe for exploration.

In conclusion, this study demonstrates the effectiveness of AI and ML models, particularly CNNs, in enhancing the quality control processes in textile manufacturing. By automating defect detection and improving operational efficiency, these technologies provide manufacturers with powerful tools to meet the increasing demands for high-quality, customised textile products. The findings of this research underscore the importance of continued investment in AI and ML technologies to drive innovation and maintain competitiveness in the textile industry. Future research should focus on expanding the scope of AI applications in textiles, exploring hybrid models, and addressing sustainability challenges through AI-driven solutions.

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Fabric defect detection: a hybrid CNN-LSTM approach using TGANet for improved classification and traceability

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ABSTRACT – REZUMAT

Fabric defect detection: a hybrid CNN-LSTM approach using TGANet for improved classification and traceability

The fashion industry is incredibly adaptable and strives to adjust to shifting fashion trends. A critical phase in the textile industry is ensuring that quality standards are met. The identification and categorisation of fabric flaws is an essential stage in the production process that keeps any defective fabric off the market. Individuals manually detected the fabric's surface flaws; however, this is time-consuming and raises issues with human error. The creation of hybrid systems based on Textile Generative Adversarial Networks (TGANet) is the result of efforts to improve the accuracy of flaw detection using image processing studies. To solve fabric pattern classification and detection issues in fabric traceability and management, Convolutional Neural Networks (CNN) and long short-term memory (LSTM) in deep learning are used to extract texture features. To enhance the feature extractor, we employ TGANet in this study. Using fabric photos to train the new CNN-LSTM, the texture features are effectively retrieved, and the fabric categories are correctly identified using classifiers that have been tuned. Multimodal datasets for textile design are used. To verify the model's robustness and generalisation, various data are used, such as training with tiny training sets and varying image sizes. The accuracy and speed of the suggested network model are 94% better than those of the traditional deep learning classification techniques.

Keywords: *deep learning, fashion industry, TGANetwork, hybrid CNN-LSTM, detection and classification, classifier*

Detectarea defectelor materialelor textile: o abordare hibridă CNN-LSTM utilizând TGANet pentru o clasificare și o trasabilitate îmbunătățite

Industria modei este incredibil de adaptabilă și se străduiește să se adapteze la tendințele modei în schimbare. O fază critică în industria textilă este asigurarea respectării standardelor de calitate. Identificarea și clasificarea defectelor materialului textil este o etapă esențială în procesul de producție, care împiedică comercializarea oricărui material defect. Persoanele au detectat manual defectele de suprafață ale materialului textil; cu toate acestea, acest lucru consumă mult timp și ridică probleme legate de eroarea umană. Crearea de sisteme hibride bazate pe rețele adversare generative pentru materiale textile (TGANet) este rezultatul eforturilor de îmbunătățire a preciziei detectării defectelor cu ajutorul studiilor de prelucrare a imaginilor. Pentru a rezolva problemele de clasificare și detectare a modelelor de materiale textile în ceea ce privește trasabilitatea și gestionarea materialelor, rețelele neuronale convoluționale (CNN) și memoria pe termen scurt lung (LSTM) în învățarea profundă sunt utilizate pentru a extrage caracteristicile texturii. Pentru a îmbunătăți extractorul de caracteristici, folosim TGANet în acest studiu. Folosind fotografii de materiale textile pentru a antrena noul CNN-LSTM, caracteristicile texturii sunt recuperate în mod eficient, iar categoriile de materiale textile sunt identificate corect folosind clasificatoare care au fost reglate. Sunt utilizate seturi de date multimodale pentru designul textil. Pentru a verifica robustețea și generalizarea modelului, sunt utilizate diverse date, cum ar fi instruirea cu seturi de instruire mici și imagini de diferite dimensiuni. Precizia și viteza modelului de rețea sugerat sunt cu 94% mai bune decât cele ale tehnicilor tradiționale de clasificare prin învățare profundă.

Cuvinte-cheie*: învățare profundă, industria modei, TGANetwork, CNN-LSTM hibrid, detectare și clasificare, clasificator*

INTRODUCTION

Defect identification and classification are essential in the fabric business because they can yield useful data for textile production quality management. Fabric flaws are traditionally examined by humans, which takes a lot of time and effort. Furthermore, the weariness brought on by prolonged effort can make this human inspection procedure ineffective. Therefore, the modern fabric business may find automated visual inspection and classification procedures desirable. Defect detection is a major problem when it comes to identifying abnormal surface areas in industrial products such as paper, textiles, aluminium plates, etc. The existence of flaws has been predicted to lower fabric prices by 45% to 65%. Since all products must be inspected for flaws, any defects must be found, fixed, or replaced to guarantee quality control in the fabric business.

Defects in fabrics are imperfections in the material that lower their quality, which lowers their usefulness and worth. It is impossible to fix or undo these flaws once they are on the market. Delivering high-quality products, therefore, requires making sure the final product is perfect. A key component of ensuring customer satisfaction and cutting manufacturing costs is quality control. During the manufacturing process, a variety of factors, including the raw material, spinning, dying, knitting, and weaving, can result in defects in the fabric. Faulty fabrics are produced as a result, which could reduce customer satisfaction. In addition to the production costs, subpar items are typically sent back to the textile mill for replacement or repair, raising the total cost. Therefore, if there are any fabric flaws, they must be found so that the producers can determine the source and take the appropriate action to address the problem [1, 2]

It is possible to get the conclusion that the majority of these studies employ a window or filter-based technique after examining these relevant works in the field of fabric defect identification. The Gabor filter analyses texture using a linear filter. Around the analysis point, it looks for any particular frequency content in the picture. The linear structure of the filter means that the flaw identification process takes too long. It records the features and converts them into a feature vector, whose dimensions continue to grow because of the filter's linearity. Redundancy of characteristics is another effect of this that lowers the recognition rate [3, 4, 5]. Deep learning, commonly referred to as Deep Neural Networks (DNN), including Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN), was developed to address the problem of insufficient processing power for massive amounts of unstructured data.

When compared to other current approaches, the suggested hybrid CNN-LSTM utilising deep learning and TGANet performs well in classification.

Breathability, temperature control, electrical information, and colour-changing material are how textiles or fabric images are categorised. The spread of coherence and the log Gabor filters lessen noise, uneven lighting, and processing flaws brought on by bogus ridges and ridge fractures in the textile photos.

Problem statement

The hybrid CNN-LSTM approach based on TGANet is utilised to enhance the fabric picture classification and detection efficiency. Coherence diffusion and log Gabor filters are applied to fabric images to extract very resilient features and noise. To improve the retrieved texture features, statistical texture transformations and texture filtering are applied. The main issues with the suggested approach include poor image quality, environmental flaws, subpar material quality, and incorrect classification. But classifying flaws according to these textural characteristics makes it difficult to identify particular flaws. Deep learning-based fabric picture classification is used to get around these flaws.

Contributions of the paper

- Combining the coherence diffusion filter with the log-Gabor filter: It reduces processing defects caused by spurious ridges and ridge fissures, as well as noise and uneven lighting in the textile images. For the filtering, a convolutional function with ReLu activation is taken into consideration.
- TGAnet: The current research proposes an enhanced TGANet to learn the reconstruction of fabric images in an unsupervised way, hence addressing the issue of the lack of defect samples. In contrast to conventional methods of detecting fabric defects, which rely on a high number of defect samples, the enhanced TGANet accepts a large number of normal fabric photos as input.
- Hybrid CNN-LSTM is used to increase the recognition accuracy level and achieve excellent performance in detection and classification compared to other existing methods.
- Deep learning algorithms are considered to make it faster and easier to analyse multiple datasets. The algorithm has led to better-quality and improved accuracy of 94 % of textile images

The structure of the paper is as follows: In the 2nd section, the literature on detection, filtering and classification is reviewed. In the 3rd section, the methodology for this experiment is explained. The experiment's results are discussed and summarised in the 4th section. The recent research is concluded in the 5th section.

LITERATURE SURVEY

Several studies have successfully employed image filters, classification and detection of textile images for highlighting defect features in fabrics.

Dataset preprocessing using filters

The most popular filters for enhancing textile qualities are the Local Binary Pattern, Gabor, and Median filters. These filters are commonly used in conjunction with other deep learning algorithms to get exceptional results for jobs involving fault identification. Utilising a variety of models, extracting GLCM and LBP features, and converting images to grayscale, an image classification technique that achieves high validation accuracy on unseen data [7]. It was possible to attain up to 70% test accuracy and 83.9% validation accuracy. A median filter for denoising and pooling operations using deep learning methods to detect fabric problems [8]. The accuracy achieved with this strategy was 90%. The sensitivity of defect identification can be increased through picture preprocessing, as these filters demonstrate.

In fabric analysis, pattern recognition techniques are essential. For pattern identification, a variety of image processing filters are available. Preprocess fabric images for classification by binarising them, filtering (smoothing with the Direct Fourier Transformation method in combination with Gaussian filtering, and compressing with the Daubechies wavelet method),

and after that, employing image processing techniques to extract pilling features (number of pilling points, area, etc.) [9].
The standard option for localising frequency and spatial data is to use Gabor filters. Since the Gabor filters only have an octave maximum bandwidth, they are not the greatest choice for those seeking broad-spectrum information with maximal spatial localisation [6]. A similar method to identify fabrics by identify the texture of wrinkles. After removing noise and converting images to LBP-like grayscale and binary formats, it extracts information such as the area-to-height, area-to-perimeter, and wrinkle width-to-length ratios. Contextual filtering, CNN filters, Gaussian, LaPlace, Gabor, and other filters are employed. However, the Log Gbor (LGF) filter is utilised because of certain loss, error, noise, complex backdrop image, poor feature extraction results, and blur defects [10].

Textile image detection

Neural networks utilised for image synthesis serve as the foundation for Generative Adversarial Networks (GANs) [11]. It is composed of a discriminator and an image-generating generator. The generator uses noise and latent space as its weights to produce images. These produced images are fed into a discriminator, which computes the error value, also known as the loss function, by comparing the produced images with actual images that are already there. The generator receives these loss functions, and it adjusts itself to create better images by responding to the loss function. The discriminator also took advantage of this mistake to improve future forecasts.
Our discriminator has an error value of 40%, for instance, if we send it an actual image and it indicates that it is 60% correct. Also, if we send the discriminator a phoney image and it indicates that there is a 70% likelihood that it is incorrect, our discriminator error is 30%, and our generator error is 70%. Both the discriminator and the generator learn from this. With each iteration, the back-propagation approach is used to alter the weights of both models. Numerous GAN variations followed, including deep convolutional GAN (DCGAN), conditional GAN (CGAN) [12, 13], and Wasserstein GAN (WGAN) [14]. Additionally, GAN is used in a variety of applications, such as data production [15, 16].
Convolutional networks were used to classify clothing designs. The task involved automatically recognising the clothing according to the newest trends in internet fashion. A deep convolutional neural network was used to achieve good results. Using two popular models, AlexNet and VGGNet [17, 18], high hand-engineered feature extraction was accomplished. The data detection function in this suggested approach is accomplished using a textile generative adversarial network.
A novel method for automated textile design pattern generation using generative models. The accuracy of state-of-the-art results in the classification of textile design patterns was improved by 2% through data cleaning and pseudo labelling [27]. Convolutional Variational Autoencoders (CVAEs) for all classes separately, and have evaluated the models using the inception score. Conditional generative adversarial network (cGAN) for fabric defect data augmentation. The image-to-image translator GAN features a conditional U-Net generator and a 6-layered PatchGAN discriminator are used in [28]. The conditional U-Network (U-Net) generator can produce highly realistic synthetic defective samples and offers the ability to control various characteristics of the generated samples.
GANs generate new images by learning features from the existing images. Features are extracted by a convolutional network, and images are generated through a deconvolutional network [29]. Different variants of GANs are available in various fields, and they have helped in many other fields, along with the field of fashion. DCGAN has been trained on all the patterns collectively up to a specific point, and the weights from the trained model have been saved. After that point, the model is trained on specific kinds of patterns, i.e., cheetah, to generate that specific kind of new pattern.

Textile image classification

Jianli and Baoqi have put forth a technique that consists of principal component analysis (PCA), NN, and grey-level co-occurrence matrix (GLCM). They employed GLCM for feature extraction and PCA to minimise the input vector's dimensionality. The high-dimensional space is represented at a low level via PCA. According to [19], these high-dimensional components are independent. To classify faults, a three-layer back-propagation neural network was employed. Fabric defect detection technology based on wavelet transform and NN [20]. To create an efficient defect system, they merged two approaches.
Artificial neural networks (ANN) are recommended for classification [21] employing supervised, reinforcement, and unsupervised learning techniques, including Multi-Layer Perceptrons, Learning Vector Quantisation, and Self-Organising Feature Maps. The MLP, LVQ, and SOFM techniques are used to classify the images into seven groups. Key depth features can be learned both intelligently and adaptively using deep learning algorithms, namely Convolutional Neural Networks (CNN). Systems for detecting fabric defects are better suited for different kinds of defects because of this capability. Every piece of input data that represents the faulty fabric image is stored in the CNN's deep structure.
CNN has also been used for positions like classifying and detecting fabric flaws. Using a modified AlexNet, [22] initially used CNN to classify defects in yarn-dyed fabrics. To classify fabric faults in a limited sample size, CNN was also used in conjunction with compressive sensing [23]. Additionally, a lot of activities involving the detection of fabric defects have been finished using CNN-based techniques. An effective unsupervised model for fabric defect identification

based on multi-scale convolutional denoising autoencoder networks [24].
LSTM has been used in several fields, such as image processing, convolution networks for classifying different materials, and anomaly detection in time series. Defect identification in fabric was found to be learning based [25, 26]. The invisible images of the fabric are categorised and segmented using LSTM-based texture classification. Labelling the trained images that are being classified is a crucial step in the texture classification process. In texture categorisation, four distinct methods are used. Co-occurrence features, greyscale differences, signed differences, and the Local Binary Pattern of micro-structures, which blends a statistical and structural approach, are the methods employed. In the field of prediction, deep learning's long short-term memory (LSTM) has exceptional processing capabilities for time series data.

PROPOSED METHOD

The main reason for using CNN-LSTM instead of LSTM is that, in contrast to other LSTM-based techniques, it can anticipate the output with high accuracy. CNN typically raises the image's level of complexity. The main outcome is that it enhances the performance of movement prediction concepts and can automatically extract high-level features. The automatic captioning of images is enhanced by the integration of CNN-LSTM. The primary goal is to resolve the time-series paradigm, and it can produce a more effective sequence plan. The procedures for textile image preparation, detection, and classification. Below is the suggested block diagram.
The hybrid CNN-LSTM-based TGANet approach for textile image recognition and classification is depicted in figure 1. The acquisition and preprocessing of the dataset is the first phase. The textile images are extracted from the textile design multimodal dataset and preprocessed by applying the log Gabor and coherence diffusion filters to eliminate mistakes and noise. The detecting step then receives the preprocessed data. The suggested TGANet technique is used to identify the filtered images during the detection phase to increase accuracy and efficiency and prevent flaws. Subsequently, the photos are supplied to the classification phase, where textile images are categorised using a hybrid CNN-LSTM algorithm.

Pre-Processing

The pre-processing involves the process of data histogram, data thinning, data binarisation, data normalisation, data validation, data cleansing, data reduction and data enhancement. To solve the issues of varying clarity, grey scale, and channel count amongst various textile images, image pre-processing was standardised. That eliminates the unwanted distribution and noise in the image. It converts different forms of words to their respective root words.

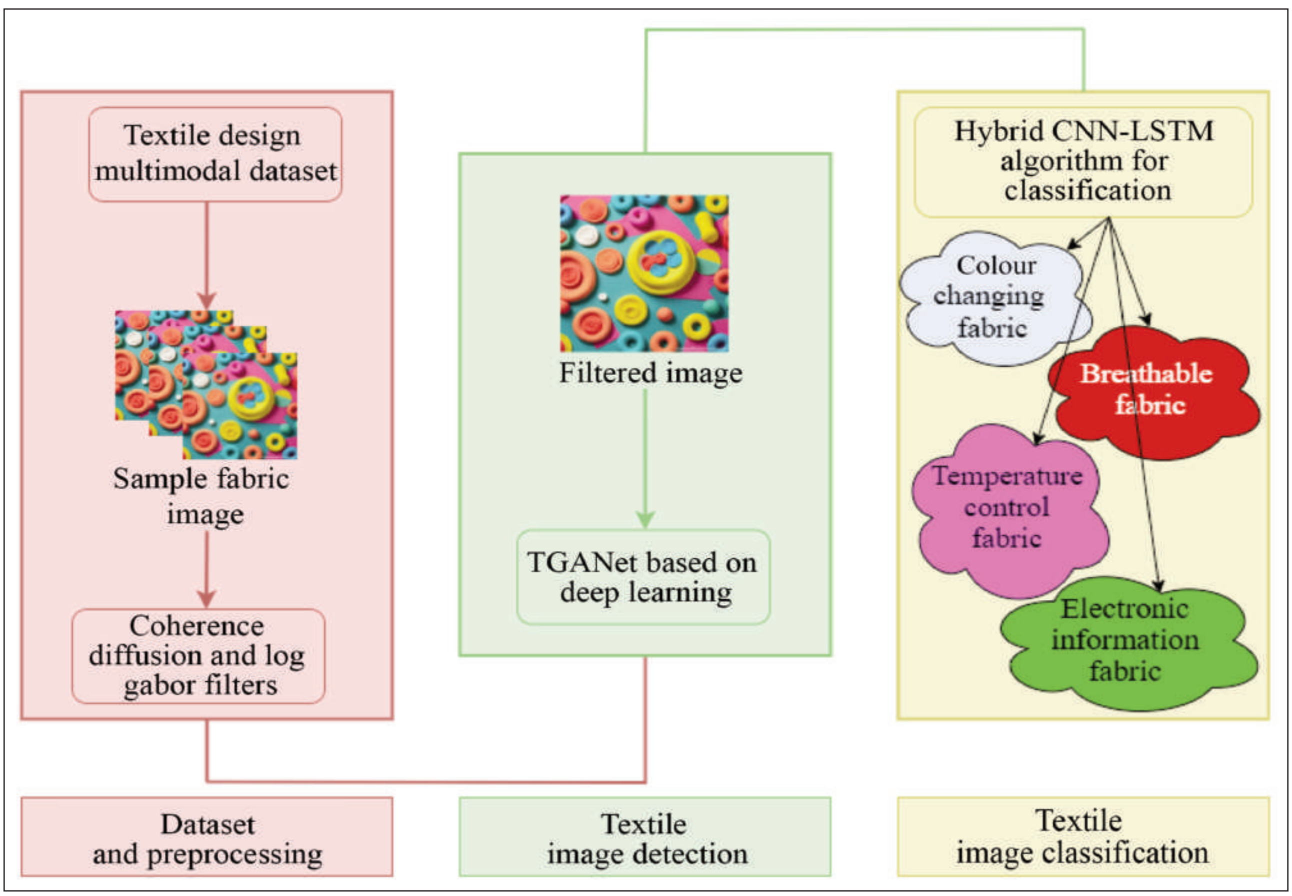

Fig. 1. Proposed block diagram

Preprocessing with filters

It is generally an edge-preserving filter. If there is any degradation in the improvement of colour saturation, the direct channel-bright method is used with certain colour factors. The general filtering equation is given below.

$$E = S(O) + \tau D \quad (1)$$

where O represents the observed image, S is the edge-preserving filtering operation, and τ is the parameter. D is the layers of the image. E is the enhanced image. Filtering is used as the template to gain the similarities between the images.

Convolutional function with the ReLu activation is considered for the filtering. Some of the filters are Prewitt, Sobel, kernel and Laplacian. All these filters are used to detect the edges along the horizontal and vertical axes.

Coherence Diffusion filter

Partial differential equations are used in the coherence diffusion filter technique, a nonlinear diffusion enhancement method, to maintain the dependence of textile image values on the gradient of neighbouring image intensities.

$$\delta t\, I = \mathrm{div}\,(D.\nabla I) \quad (2)$$

$$D = \frac{1}{1 + (||\nabla|| k)2} \quad (3)$$

where “I” denotes the image gradient, “div” denotes the divergence operator, “D” denotes the diffusion tensor, and “k” is the matching constant.

Log Gabor Filter

The log-Gabor filter helps to minimise noise and uneven lighting in the textile image, as well as processing flaws brought on by false ridges and ridge fissures. The Log-Gabor filter consists of two pieces. The following displays the angular frequency response and the radial filter frequency response.

$$G(f) = \frac{f_0}{f} \exp\left(\frac{-(\log(f/f_0))^2}{2(\log(\sigma/f_0))^2}\right) \quad (4)$$

$$G(f,\theta) = \exp\left(\frac{-(\log(f/f_0))^2}{2(\log(\sigma/f_0))^2}\right) \exp\left(\frac{-(\theta-\theta_0)^2}{2\sigma_\theta^2}\right) \quad (5)$$

Multiplying them together provides us with the log-Gabor filter:

$$G(r,\theta) = Gr(r) \cdot G\theta(\theta) \quad (6)$$

where the log-Gabor filter is constructed using the Polar coordinate (r,θ), the local centre frequency f_0, the local orientation angle θ_0, the scale bandwidth σ_f, and the angular bandwidth σ_θ the filter's response is managed by these four settings. The angular and radial components are the two parts that make up the log Gabor filter bank. To create Log-Gabor filters, some parameters are also needed, including the following: The smallest scale filter's wavelength determines the lowest frequencies that the filter wants to cover. The quantity of filter scales. How many different filter orientations can be used. The ratio of the standard deviations of the angular Gaussian spreading function to the angular spacing between filter orientations controls the angular overlap of the filter transfer functions.

Minutiae feature extraction

Feature extraction is an important part in recognition tasks, predicting performance, and it reduces the computation. All these are done by using the feature selection method. A key feature in textile image identification is the feature extraction to make it more accurate and run time to improve the accuracy. In this method, extraction is done through CNN using deep learning. The feature extraction includes the process of filtering, clustering, fusion and mapping. The extraction is normally of two types. They are knowledge-based and a deep learning-based method. The DL method performs automatic feature extraction. The extraction is done through the convolution function, that the function will refine the pixel properties, such as sharpening, deblurring, and finally enhancing the edges to strengthen the security.

TGANet Detection

Textile Generative Adversarial Networks (TGANs) are used to enhance photos and generate images, videos, and 3D scenes. When it comes to picture production, TGANets create new images by extracting features from preexisting ones. The majority of these designs consist of a single repeating pattern. To build the entire design, the designers must first generate these patterns, which are then photoshopped. Designers can get ideas for new designs by using TGANets to generate textile patterns. It has been suggested that TGANets create new patterns to accomplish this aim. There are several TGANet variations in use, and they have aided numerous other sectors besides fashion.

Figure 2 shows the basic architecture of TGAnet. TGANet is a generative model that is mostly used for image production and has its theoretical foundation in zero-sum game theory. The authors simultaneously trained two deep learning models, a discriminative model called ‘D’ and a generative model called ‘G’,

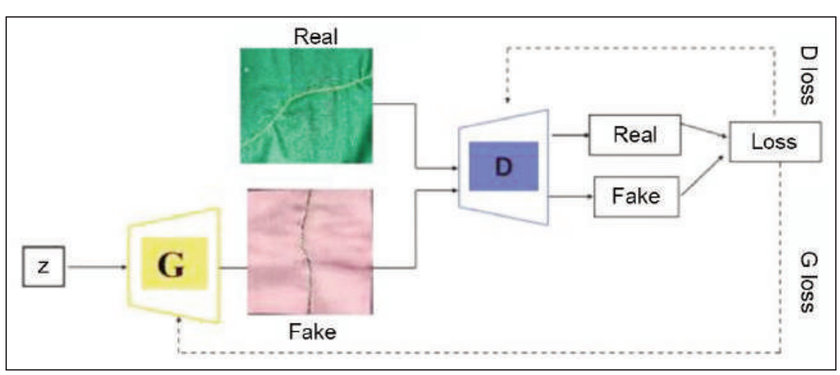

Fig. 2. Basic TGAnet architecture

using a min-max optimisation framework. The idea behind this strategy is a zero-sum game, in which the goal of one player is to maximise their gain and the goal of the other is to minimise their loss. To improve the training stability, this update involves removing the pooling layers and adding Batch Normalisation between the convolutional layers and the activation functions. Fully connected hidden layers are eliminated in favour of deeper designs. The generator employs ReLU activation for internal layers for the output, while the discriminator uses LeakyReLU throughout. These changes collectively improve training and output quality in the Textile Generative Adversarial Network.

Hybrid CNN-LSTM classification

The CNN-LSTM technique is used to improve the image's accuracy level and address less reliable image faults. The image's features are extracted using a CNN architecture-based deep learning model, and the extracted output is then fed into an LSTM input to carry out the extraction's prediction (figure 3). Complex patterns that are exceedingly difficult to learn using conventional methods can be learned via LSTM. CNN-LSTM is a multiple-layered algorithm. Time Distributed Layer, Flatten Layer, LSTM Layer, Dropout Layer, Dense Layer, and Output Layer; 1D Convolution Layer, Dropout Layer, 1D Maxpool Layer, and so forth are the layers that make up this. This can automatically extract feature information. Below is a block schematic of the Integrated CNN-LSTM.

The prediction accuracy of CNN-LSTM is higher than the single LSTM model, which reduces the training time. The hybrid CNN-LSTM, which extracts the traffic network data features and provides better intrusion detection systems. It also improves the memory utilisation, speeds up the processing and improves the robustness. In this method, the first block consists of a pooling and consensual layer, and the second block, that is the LSTM block, has a dense-based layer to increase the efficiency level. In the hybrid CNN-LSTM method, the linear layer is introduced after the CNN layer, which reduces the dimensions without any reduction in the accuracy. In this method, the first block consists of a pooling and consensual layer, and the second block, that is the LSTM block, has a dense-based layer to increase the efficiency level. It also shows the accuracy of the RMSE value:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - x_j)^2} \quad (7)$$

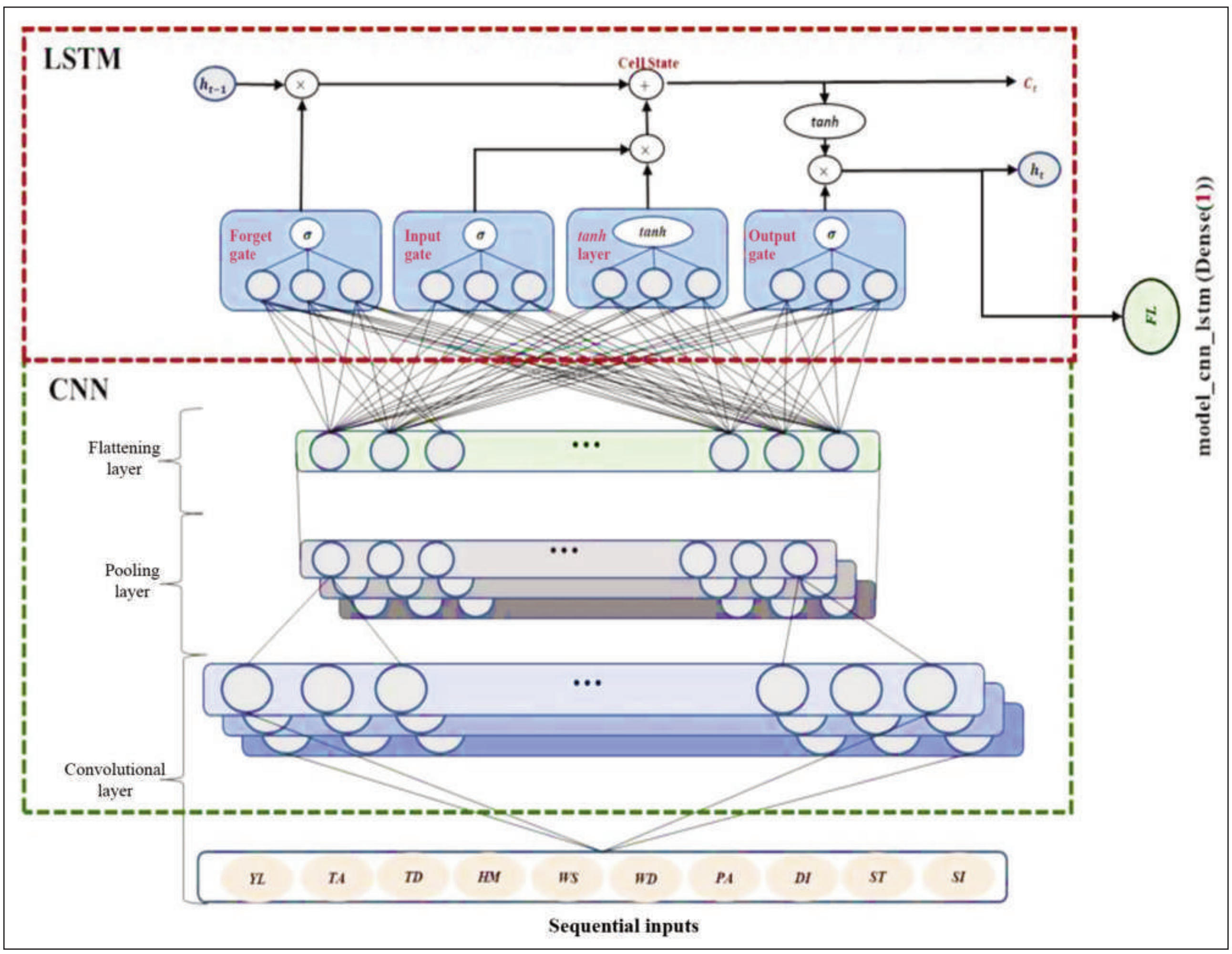

Fig. 3. The proposed hybrid CNN-LSTM architecture

where N is the number of errors. x_i is the observed value and x_j is the forecasted value. The value will be approximately equal to 1 using the deep learning method. The accuracy measurement is given below.

$$Accuracy = \frac{Message\ that\ was\ correctly\ predicted}{total\ number\ of\ predicted\ messages} \quad (8)$$

ReLU expression can be represented as,

$$ReLU(x) = f(x) = \max(0, x) \quad (9)$$

where *ReLu* is a Rectified Linear Unit of X, will be the maximum value of x along the x-axis and 0 along the y-axis. Followed by the down-sampling layer is known as the max-pooling layer. That expresses the generalisation and convergence of the image to reduce the noise. The basic formula for the LSTM using the deep learning method is as follows:

$$h_t = \sigma\,(Wi,\ h \cdot x_t + Wh,\ h \cdot h_{t-1} + b) \quad (10)$$

whereas W represents the weight of the input and the hidden layers. b is the hidden vector bias. x is a sample of the image. CNN is used for the extraction purpose, and the LSTM is used for the classification.

Performance analysis

Different performances are used to analyse the accuracy measurements. Each of the metrics is defined by the formulas below.

Accuracy: The message was correctly predicted among the total number of predicted messages.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (11)$$

Sensitivity: It is the ability to translate expected positive numbers into unquestionably positive ones.

$$Sensitivity = \frac{TP}{TP + TN} \quad (12)$$

Specificity: It is a statistic used to predict the presence of true negatives.

$$Specificity = \frac{TN}{TN + TP} \quad (13)$$

where TP is the number of classifications that were true positives. To put it another way, FP stands for false positives, TN for true negatives, and FN for false negatives.

RESULT AND DISCUSSION

A textile image multimodal dataset comprising 8000 photos with categories for broken thread defects, seam puckering, and uneven stitching was used to train TGANet. We used a mini-batch training strategy to increase training efficiency and prevent loading all images into memory at once. We created a sample plot for local visual assessment for each of the 40 training batches. We produced a variety of samples with a range of faults using TGANet. The sample dataset photos are displayed in figure 4.

To eliminate noise, error, patches, clarity, and environmental flaws, the dataset samples are filtered using the log Gabor and coherence diffusion filters. Additionally, figure 5 compares photos with and without filters.

The comparison of different detection strategies is provided below. The evaluation of current techniques like GAN, DCGAN, CGAN, WGAN, Alexnet, and VGGnet. To determine the detection efficiency and degree of correctness of the identified textile images, the suggested TGAnet is contrasted with all of these current techniques.

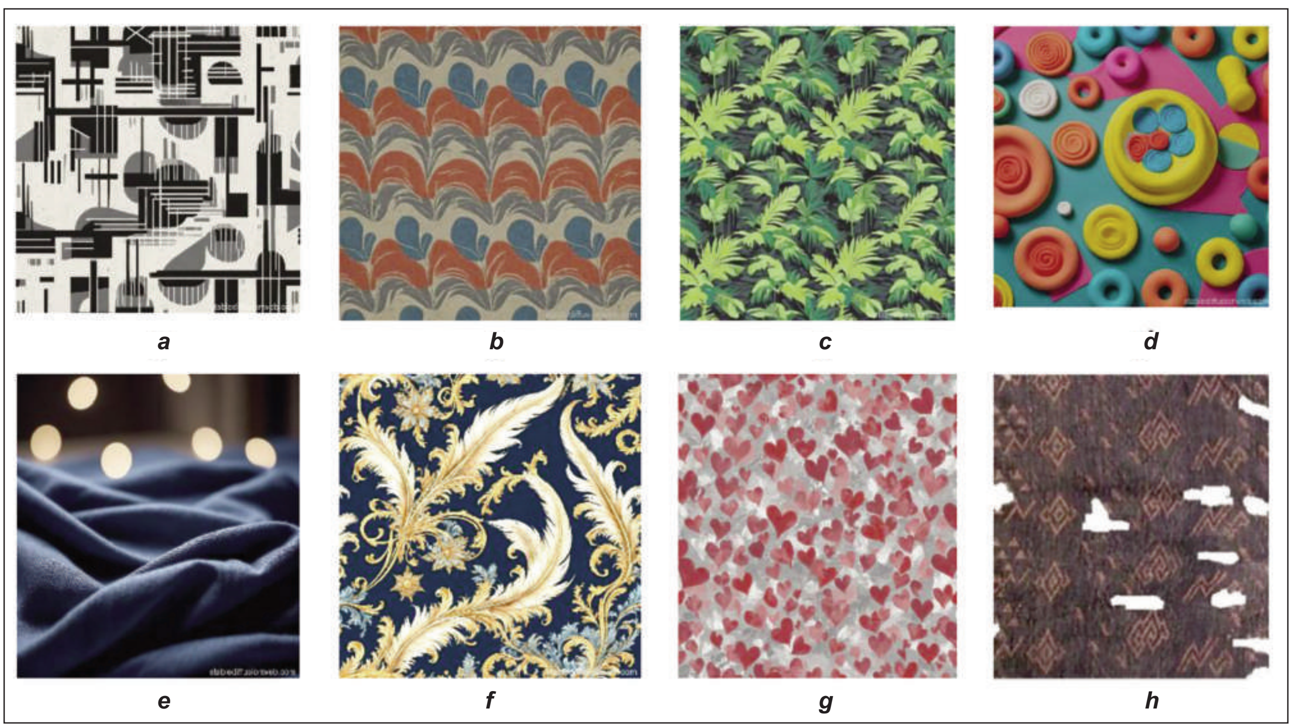

Fig. 4. Sample textile images from the dataset

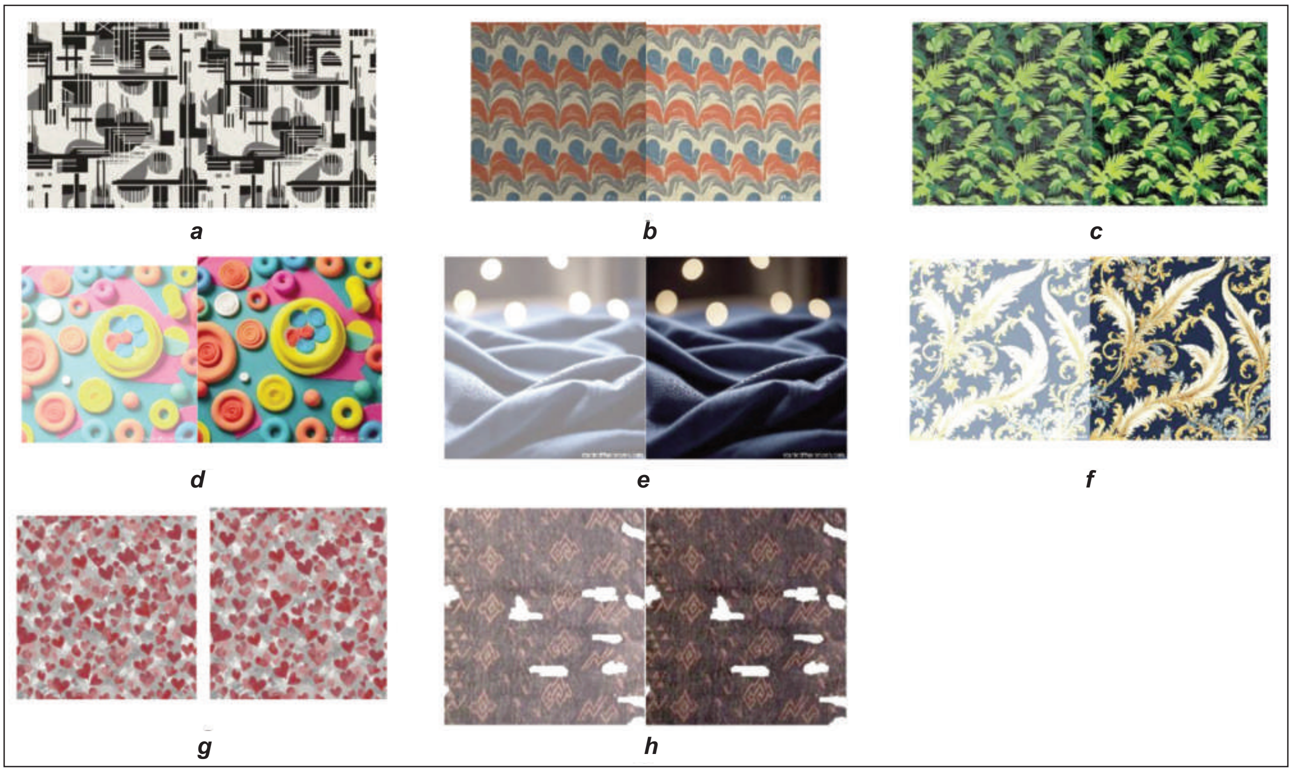

Fig. 5. Comparison of sample images vs filtered images

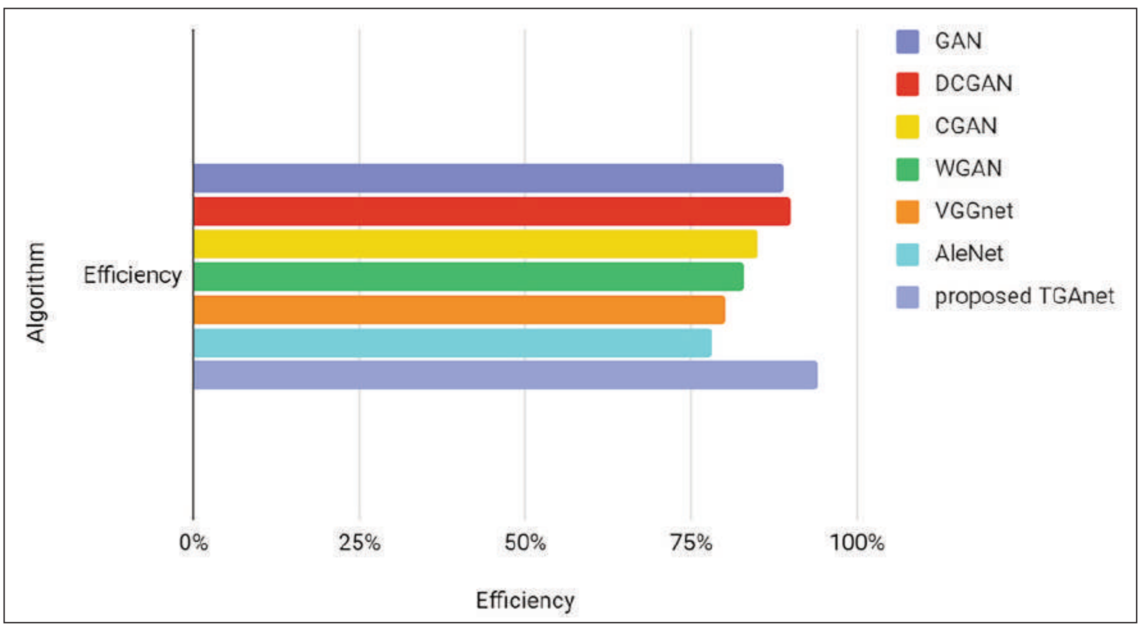

Fig. 6. Graph of detection efficiency vs algorithm

The detection efficiency level is displayed in figure 6. The detection efficiency of the GAN algorithm is 89%. 90% of the detection efficiency is provided by the DCGAN. The detection efficiency is 83% for the CGAN algorithm and 85% for the WGAN algorithm. While the Alexnet offers 78% efficiency, the VGGnet offers 80% efficiency. Additionally, the suggested TGANet algorithm offers the highest efficiency rate of all the current techniques, with a detection accuracy level of 94%.

The table below shows the classification accuracy of various existing and proposed classifiers for the textile images.

The classifiers and accuracy levels of the different classifiers used for the textile picture classifications are displayed in table 1. The accuracy of 78% was obtained using a principal component analysis method based on GLCM. The accuracy of the ANN-based deep learning approach is 68%. 79% accuracy is produced via SVM. The accuracy of the LSTM is 80%, while the accuracy of the generic CNN alone is 83%. The results of these two classifiers are better. Therefore, the suggested approach combines the CNN and LSTM hybrid forms to improve deep learning categorisation of textile photos.

The effectiveness of two distinct textile image categorisation examples is displayed in table 2. CNN produces results that are superior to those of the LSTM method when compared to the three methods mentioned above. However, the outcomes of the suggested approach are superior to those of the other three.

Table 1

COMPARISON OF CLASSIFIERS AND ACCURACY LEVELS	
Classifier	**Accuracy level**
GLCM	78
ANN	68
NN	70
SVM	79
LSTM	80
CNN	83
Proposed hybrid CNN-LSTM	**85**

Table 2

CLASSIFICATION EFFICIENCY FOR DIFFERENT CLASSIFIERS								
Sample images	**Colour changing fabric**		**Temperature control fabric**		**Electronic information fabric**		**Breathable fabric**	
	CNN	75	CNN	62	CNN	52	CNN	65
	LSTM	72	LSTM	59	LSTM	50	LSTM	60
	CNN-LSTM	78	CNN-LSTM	68	CNN-LSTM	56	CNN-LSTM	70
	CNN	68	CNN	59	CNN	50	CNN	68
	LSTM	62	LSTM	55	LSTM	53	LSTM	65
	CNN-LSTM	70	CNN-LSTM	63	CNN-LSTM	57	CNN-LSTM	73

CONCLUSION

An essential component of the production process, image-based quality control seeks to identify material irregularities. The intricacy and diversity of products, flaws, and the infrequency of flaws pose difficulties. Therefore, manual inspection is still a major component of quality control. Performance has significantly improved with supervised, data-driven techniques. By using the uniformity of defect appearance across fabrics to convey information about anomalies from one fabric to another, we get around this limitation. Deep learning detection based on TGANet is thought to increase accuracy and efficiency. The images are improved, and the noise is eliminated by applying the log Gabor and coherence diffusion filters. To categorise the photos according to specific criteria, hybrid CNN-LSTM based deep learning classifiers are employed. The future work can be performed with different filters or any other hybrid deep learning methods for the classification of textile images.

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A fast multi-scale textile pattern generation method combining layered loss and convolutional attention

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ABSTRACT – REZUMAT

A fast multi-scale textile pattern generation method combining layered loss and convolutional attention

This paper introduces a neural network-based algorithm for the rapid multi-scale synthesis of textile patterns. The algorithm achieves comprehensive textile pattern style reconstruction by utilising low-level feature loss, represented by the Gram matrix, to capture colour and texture, and high-level feature loss, represented by the Wasserstein distance, to capture complex structures and semantic content. The convolutional attention feature enhancement module is incorporated to improve pattern detail clarity and overall visual quality by emphasising significant features and suppressing irrelevant information. Furthermore, the multi-scale optimisation module enhances texture and layering by optimising the image at different scales. Experimental results demonstrate that, compared to existing methods, this approach offers superior visual effects in pattern synthesis and scalability in pattern size. It not only generates high-quality textile patterns but also excels in managing complex textures and maintaining semantic consistency. This method aids designers in extending pattern designs and advances the intelligent development of textile design and production.

Keywords: *textile pattern design, neural network, attention mechanism, style loss, intelligent design*

O metodă rapidă de generare multi-scală a modelelor textile care combină pierderea stratificată și atenția convoluțională

Această lucrare prezintă un algoritm bazat pe o rețea neurală pentru sinteza rapidă multi-scală a modelelor textile. Algoritmul realizează o reconstrucție cuprinzătoare a stilului modelelor textile prin utilizarea pierderii de caracteristici de nivel scăzut, reprezentată de matricea Gram, pentru a capta culoarea și textura, și pierderea de caracteristici de nivel înalt, reprezentată de distanța Wasserstein, pentru a capta structuri complexe și conținut semantic. Modulul de îmbunătățire a caracteristicilor atenției convoluționale este încorporat pentru a îmbunătăți claritatea detaliilor modelului și calitatea vizuală generală prin accentuarea caracteristicilor semnificative și suprimarea informațiilor irelevante. În plus, modulul de optimizare multi-scală îmbunătățește textura și stratificarea prin optimizarea imaginii la diferite scale. Rezultatele experimentale demonstrează că, în comparație cu metodele existente, această abordare oferă efecte vizuale superioare în sinteza modelelor și scalabilitate în dimensiunea modelelor. Aceasta nu numai că generează modele textile de înaltă calitate, dar excelează și în gestionarea texturilor complexe și menținerea coerenței semantice. Această metodă îi ajută pe designeri să extindă modelele și promovează dezvoltarea inteligentă a designului și producției textile.

Cuvinte-cheie*: model textil, rețea neuronală, mecanism de atenție, pierdere de stil, design inteligent*

INTRODUCTION

Pattern design is a crucial aspect of textile design [1]. Traditionally, designers extensively explore sources of inspiration [2], extracting core elements such as structure, perspective, lines, texture, and colour. These elements are then used to upgrade and recreate the artistic essence of the inspiration materials through hand-drawing or software [3], ultimately completing the pattern design. This process tests the designer's artistic imagination, perspective selection, information collection, and abstract expression skills, and is extremely time-consuming and labour-intensive. In recent years, the adoption of new digital technologies has enabled the automatic recombination of core elements from inspiration materials, rapidly generating a large number of pattern drafts for designers to choose from [4]. This approach not only significantly improves design efficiency but also enhances the designer's creativity and imagination. This trend is set to become a new standard in the field of textile pattern design.

In the field of computer image design, the rapid development of deep learning technology based on convolutional neural networks has driven research in textile image generation [2–6]. Li et al. [5] achieved camouflage pattern generation using the CycleGAN algorithm. Wu et al. [6] employed generative adversarial networks (GANs) to create fashionable Dunhuang-style clothing. Liu et al. [7] utilised conditional GANs for innovative designs of traditional Chinese textile patterns. However, GANs face several challenges, including training instability, the need for large datasets, long training times, high computational power requirements, and difficulty in generating high-resolution images [8]. Karagao et al. [9] employed diffusion models for textile pattern generation, while Xie et al. [10] proposed a multi-stage diffusion model that integrates high-level design concepts with low-level clothing attributes for generating and editing fashion design drafts. Although diffusion models produce high-quality images, they demand even greater GPU computational power, limiting their practical application due to high computational costs.

Style transfer, as a significant branch of image generation technology, enables the application of one image's style to another, imbuing it with a new artistic flair to create a novel image. Compared to other image generation technologies, style transfer offers greater flexibility and fewer usage restrictions, making it highly applicable in computer art and visual design. This capability opens up innovative possibilities for textile pattern design. Some researchers have already applied it to textile pattern generation. For instance, Sun et al. [11] developed a fast textile pattern generation algorithm combining Markov Random Fields (MRF) and Gram methods, while Qiu et al. [12] proposed a colour-optimised local pattern style transfer method for fabrics.

Style transfer originates from non-photorealistic rendering (NPR) and is closely related to texture synthesis and texture transfer. Gatys et al. [13] pioneered neural style transfer by extracting image features using convolutional neural networks and constructing Gram matrices to capture image styles, achieving oil painting style transfer through high-level feature processing. This method remains a gold standard today. Subsequently, Johnson et al. [14] introduced a fast style transfer algorithm, enabling rapid image style transfer through iterative optimisation of the generation model. Li et al. [15] proposed a neural style transfer method based on patch matching using MRF. However, due to the high computational cost of numerous patch matches, the method has long running times and struggles with images exhibiting large-scale structural differences. The introduction of the Wasserstein distance improved the measurement of image style distribution differences, enhancing style transfer quality [16–20]. However, its high computational complexity limits its direct application in neural style transfer [16].

Despite these advancements, applying neural style transfer to textile pattern generation still faces limitations. Existing methods are predominantly used for abstract creations like artistic paintings, focusing on the transfer and reconstruction of global style features and local texture features while neglecting the integrity of semantic structure features in patterns [20]. Additionally, during the generation process, local structural information is often incomplete, leading to artefacts in areas of repeated textures, thereby affecting pattern quality. Textile pattern design, unlike abstract art, requires the preservation of the complete regularity of local pattern structures. Capturing and transferring complex style features while maintaining the integrity of local structures and enhancing visual naturalness and generation efficiency remains a challenge.

To address these issues, this paper proposes a multiscale style transfer algorithm for textile pattern generation, incorporating hierarchical style loss optimisation and convolutional attention feature extraction. This approach maintains the integrity of local semantic structures in style images during pattern generation, resulting in improved visual effects. It is well-suited for textile pattern generation and demonstrates higher generation efficiency compared to similar methods.

TEXTILE PATTERN GENERATION ALGORITHM

The textile pattern generation model proposed in this paper consists of four modules: the initialisation module, the feature extraction enhancement module, the loss calculation module, and the multiscale optimisation module, as shown in figure 1. First, the target pattern is input, and style initialisation is performed. Depending on the input image size, a multiscale division is conducted to generate an optimisation pyramid sequence for the pattern. The feature network extracts the pattern's style features, and the channel spatial attention module enhances and integrates these features at the style layer. The loss calculation module computes the feature loss at different levels, and combined with the multiscale optimisation module, iterative optimisation of the pattern is performed at different scales, ultimately generating a new style pattern.

Style loss function

In this paper, the VGG19 network is used as the style feature extractor. It retains 16 convolutional layers and removes the original fully connected layers to reduce computational overhead. All pooling layers are replaced with average pooling to better preserve global information and reduce overfitting. The network layers {conv1_1, conv2_1, conv3_1, conv4_1, conv5_1} are selected as style layers, and the style feature extraction layers are designated as Layer1-5. The shallow layers (close to the input layer) of the network mainly capture primary features such as edges, textures, and colours, while the deep layers capture more complex structures, content objects, and style patterns [25].

The style loss function is a core component of image style feature reconstruction [25], crucial for the overall style effect of the generated image. Previous studies [13–16] typically used a single style loss function for image style reconstruction, which can quickly complete the reconstruction of the pattern style but often fails to adequately represent both low-level and high-level features. This paper employs a hierarchical approach, combining different style losses to simultaneously express low-level and high-level features.

To better reconstruct style features at different levels, this paper uses Gram matrices for the shallow low-level

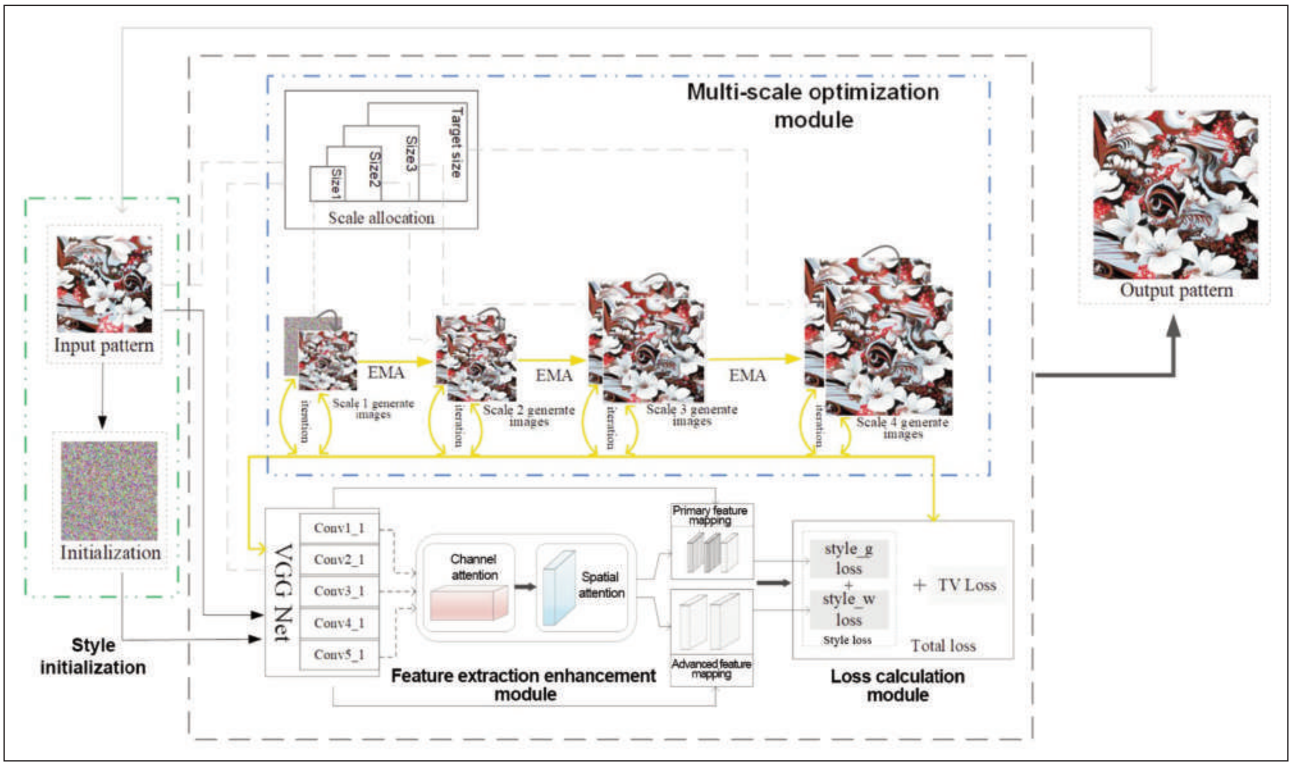

Fig. 1. Overall framework of the algorithm (arrows indicate the flow direction)

features extracted by Layer1, Layer2, and Layer3 in the network. These features mainly express the stylistic elements of the image, with little association to specific spatial structures. Gram matrices effectively capture fundamental texture and colour information [13]. Unlike traditional mean-squared error quantification of Gram matrix differences, shallow features are primarily edges, corners, and colour blocks, and their quantity is far less than the number of pixels. Therefore, this paper normalises features by dividing by the number of features. This approach balances the contribution of features rather than the overall pixel count, which is beneficial for expressing primary features. The feature-normalised Gram matrix is defined as:

$$G_{ij}^{norm} = \frac{\sum_k F_{ik} \cdot F_{jk}}{C} \quad (1)$$

where F_{ik} represents the feature value of the i^{th} channel at position k in the feature map of the input image, F_{jk} is the feature value of the j^{th} channel at the same position, and C denotes the number of channels in the feature map.

To calculate the mean error between the Gram matrices of target features and generated features, gradient normalisation is employed to mitigate numerical issues during parameter updates, thus enhancing the stability of the iterative process. The formula for calculating the shallow layer style loss function based on the Gram matrix is as follows:

$$L_{style_g} = \frac{\sum_{i,j}\left(G_{ij}^{norm}(g) - G_{ij}^{norm}(s)\right)^2}{\sum_{i,j}\left|G_{ij}^{norm}(g) - G_{ij}^{norm}(s)\right| + \epsilon} \quad (2)$$

Where $G_{ij}^{norm}(s)$ and $G_{ij}^{norm}(g)$ represent the feature-normalised Gram matrices of the style image and the generated image, respectively. The term ϵ is a regularisation term to avoid division by zero during computation.

Since Gram matrices do not preserve spatial information [19, 20], they struggle to accurately represent the structure and semantic information of high-level features, making it easy to overlook the content and complex components of the image in style reconstruction. For the high-level features extracted by Layer4 and Layer5, this paper uses the mean and covariance matrices to jointly describe the feature distribution of the target image and the generated image. By calculating the Wasserstein distance under a Gaussian distribution as the style loss, this approach better preserves spatial information and more comprehensively expresses the style information of deep features.

The specific method is as follows. First, compute the mean vector μ and the second-order raw moment matrix S of the input feature map and the target feature map at Layer4 and Layer5. The formulas are as follows:

$$\mu = \frac{1}{HW} \sum_{h=1}^{H} \sum_{w=1}^{W} X_{chw} \quad (3)$$

$$S = \frac{1}{HW} \sum_{h=1}^{H} \sum_{w=1}^{W} X_{chw} X_{dhw} \quad (4)$$

where H and W represent the height and width of the feature map, respectively, and c denotes the channel index.

Using the mean μ and the second-order raw moment S, the covariance matrix Σ of the features is calculated as follows:

$$\Sigma = S - \mu\mu^T + \epsilon I \quad (5)$$

Where ϵI is a regularisation term added to avoid numerical instability in the computation, and I is the identity matrix.

The squared difference of the feature means and the sum of the differences of the covariance matrices are used to approximately calculate the Wasserstein distance, which serves as the style loss for deep features L_{style_w}. The calculation method is as follows:

$$L_{style_w} = ||\mu_x - \mu_t||^2 + Tr\left(\Sigma_x + \Sigma_t - 2\left(\Sigma_t^{1/2}\Sigma_x\Sigma_t^{1/2}\right)^{1/2}\right) \quad (6)$$

where μ_x and μ_t represent the mean vectors of the input and target style image features, and Σ_x and Σ_t represent the covariance matrices of the input image features and the target style image features, respectively.

The total style loss function is:

$$\mathcal{L}_{style} = \Sigma_{i=1}^{3} w_l \cdot L_{style_g} + L_{style_w} \quad (7)$$

Where w_l denotes the loss weight of the l layer in the style layers, controlling the balance between the details and the overall structure in the generated image.

Convolutional attention feature enhancement module

The attention mechanism imitates human visual function by focusing on different parts of an observed object to varying degrees, filtering out redundant information, and retaining key information. This mechanism enables networks to concentrate on the main semantic structures of images and the critical texture strokes of style images [21–23]. Inspired by the CBAM attention mechanism [24], this paper incorporates a convolutional attention module into the feature extraction process, which includes both channel attention and spatial attention. The structure is depicted in figure 2.

Channel attention is represented as a diagonal matrix, with each diagonal element representing the channel weight. Feature information is extracted through average pooling and max pooling, then input into a multilayer perceptron (MLP) to learn the relationships between channels. The output of the MLP is element-wise summed, and the channel contribution is regulated by the Sigmoid activation function. The method is detailed as follows:

$$M_{chanle}(F) = \sigma\left(MLP(AvgPool(F_s)) + MLP(MaxPool(F_s))\right) \quad (8)$$

where σ denotes the Sigmoid activation function, and F_s is the input feature map.

Spatial attention is calculated as a full matrix, generating an attention feature map using global information. The design principle of this module is to maintain feature expressiveness while being lightweight and effectively capturing key features. By applying average pooling and max pooling operations to compress the channel dimensions of the feature F'_s, followed by convolution concatenation and Sigmoid activation, the final spatial attention feature map is generated. The process is represented as follows:

$$M_{spatial}(F'_s) = \sigma\left(conv_{3\times3}([AvgPool(F'_s);MaxPool(F'_s)])\right) \quad (9)$$

where $conv_{3\times3}$ denotes a 3×3 convolution.

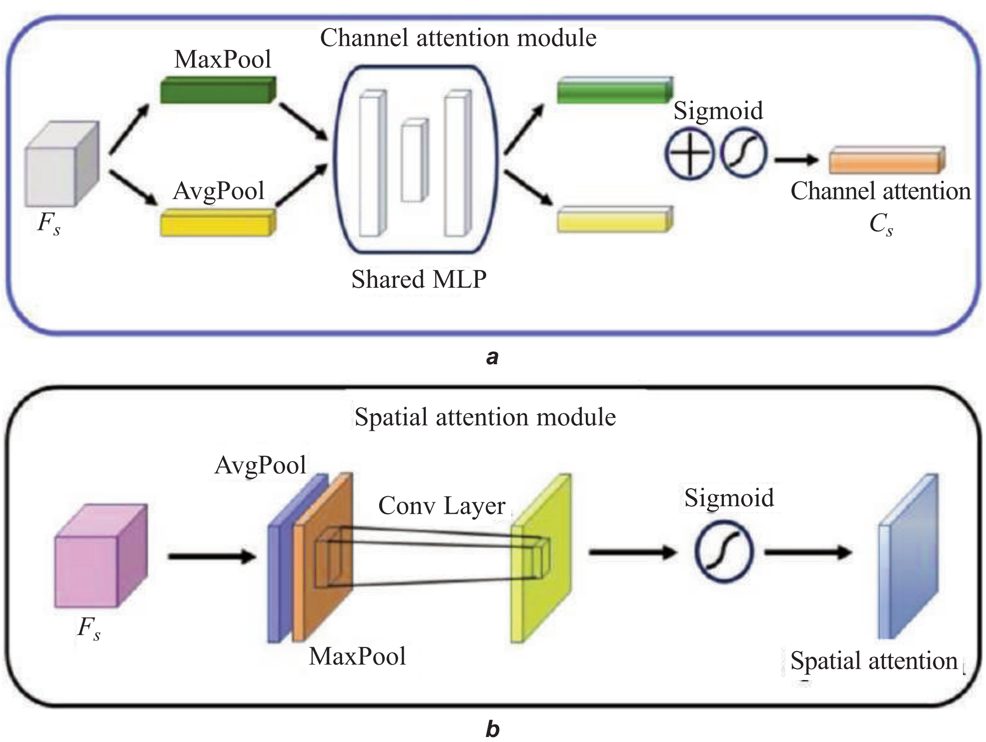

Fig. 2. Convolutional attention feature structure: *a* – Channel attention module structure; *b* – Spatial attention structure

To efficiently optimise the extracted features, inputs are derived from Layer1 and Layer3 in the shallow layers and Layer5 in the deep layers of the feature extraction network. The channel and spatial attention mechanisms are concatenated for feature refinement. The refined output features, combined with other layer features, are then used as style feature inputs into the multiscale optimisation module. Style image synthesis is jointly optimised using the feature loss functions L_{style_g} and L_{style_w} , as well as the total variation (TV) loss. This process is illustrated in figure 1.

Multiscale image optimisation module

The core idea of multiscale optimisation is to progressively optimise the image from low resolution to high resolution. This approach reduces computational cost and the risk of local optima associated with high-resolution optimisation, while maintaining global structure and refining details. First, define the scale range, from the minimum scale factor S_{min} to the maximum scale factor S_{max}, with a series of resolutions, each decreasing by a factor of $\sqrt{2}$. Each scale corresponds to a specific image resolution. Next, generate the initial image using the mean and variance of the style image to preserve the style structure and enhance image diversity.

To further improve the optimisation effect, an exponential moving average (EMA) method with bias correction is introduced during the multiscale optimisation process [26]. This method smooths the image update process, reduces noise and oscillations, and makes the generated images more stable and natural. The EMA update method is:

$$\boldsymbol{A}_t = \alpha \boldsymbol{I}_t + (1 - \alpha)\boldsymbol{A}_{t-1} \quad (10)$$

where $\boldsymbol{A}_t$ represents the EMA value after the th iteration, $\boldsymbol{I}_t$ represents the image after the t^{th} iteration, and α is the decay coefficient.

To ensure continuity and smoothness between different scales, scaling and bicubic interpolation sampling are used to adjust the image. Subsequently, the style image features at the current scale are calculated, and the style target is generated using the L_{style_g} and L_{style_w} losses for feature reconstruction. To optimise the quality and realism of the synthesised image, the total variation (TV) loss function [27] is added. The TV loss reduces noise and smooths the image by penalising local pixel value variations. The TV loss function is expressed as:

$$\mathcal{L}_{TV} = \Sigma_{i,j}\left((I_{i,j} - I_{i+1,j})^2 + (I_{i,j} - I_{i,j+1})^2\right) \quad (11)$$

Combining the L_{style_g}, L_{style_w} and TV loss, the total loss function is used to calculate the overall loss. This loss is backpropagated to update the image, and the optimised image is used as the initialisation for the next scale. The total loss function is expressed as:

$$\mathcal{L}_{toal} = \alpha\mathcal{L}_{style} + \beta\mathcal{L}_{TV} \quad (12)$$

where α and β are the weights of the respective loss terms.

EXPERIMENTS AND RESULTS

This paper utilises a dataset of collected textile patterns as the style images, with each image having dimensions set to 512×512. The experiments were conducted on a computer equipped with an NVIDIA RTX 3060 GPU, an Intel i7 processor. The deep learning framework used was Pytorch, and the programming language was Python. All experimental codes and models were implemented and executed in the aforementioned environment.

Comparison of experimental results of loss functions

This paper compares the reconstruction effects of different loss functions on the style layers through experiments and analyses the rationality of the combined loss function strategy. The experimental results show that using L_{style_g} and L_{style_w} loss functions on different feature layers result in significant differences in image synthesis effects.

Figure 3 shows the synthesis results of these two loss functions. Figure 3, *a* illustrates the results using L_{style_g} loss, and figure 3, *b* illustrates the results using L_{style_w} loss. The first layer of feature mapping mainly reconstructs primary features such as colour and texture; the second and third layers extract relatively complex texture features; the fourth and fifth layers capture high-level features, such as the semantic structure of floral shapes. For the first to third layers of features, the two loss functions do not differ much in the overall structure, but the images synthesised using L_{style_g} loss are smoother, especially in terms of colour and texture. In the fourth layer of feature mapping, the images reconstructed using L_{style_w} loss retain the complete floral structure and appear natural, whereas the images with L_{style_g} loss have distorted and unnatural floral structures. The fifth layer contains the most image feature mappings; using L_{style_g} loss results in a more chaotic structure, while L_{style_w} loss can reconstruct the floral pattern features more naturally.

As presented in table 1, in 500 iterations, the average time per layer for L_{style_g} loss is 43.5 seconds, and for L_{style_w} loss, it is 99.2 seconds. The latter has a higher computational cost but better effects on high-level feature layers. Therefore, to improve efficiency while ensuring the reconstruction effect of high-level feature layers, a combined loss strategy is adopted: L_{style_g} loss is used for the first three layers, and L_{style_w} loss is used for the last two layers.

Figure 4 shows the effects and synthesis time comparison of various loss functions. Figure 4, *a* is the textile print pattern used as the style image. Figure 4, *b* shows the pattern synthesised using L_{style_g} loss, where the floral pattern structure is distorted and messy, appearing unnatural. Figure 4, *c* shows the pattern synthesised using L_{style_w} loss, where the pattern structure is coherent but local textures are unclear, and the colour details are dull. Figure 4, *d* shows the pattern synthesised using the

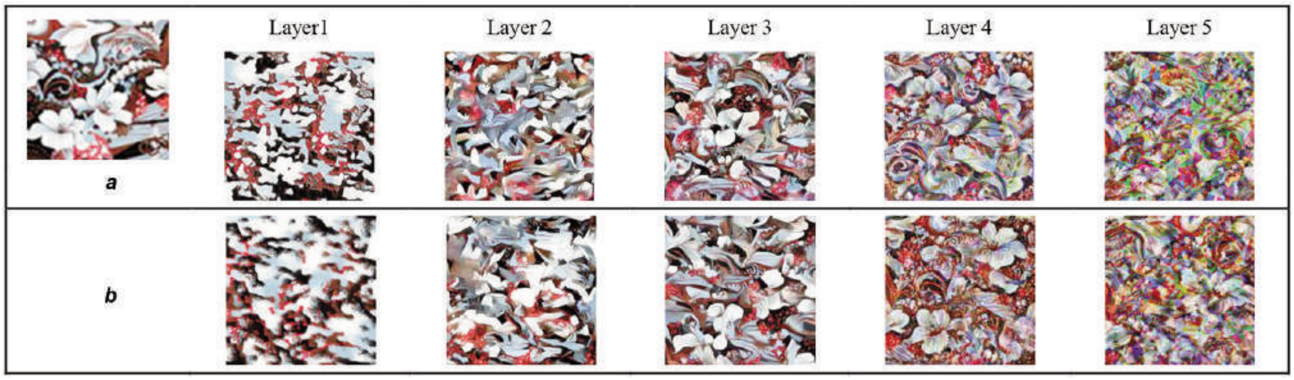

Fig. 3. The effect of different losses on image synthesis at different feature layers

Table 1

SINGLE LAYER TIME CONSUMPTION FOR DIFFERENT LOSS FUNCTIONS					
Method	**Time**				
	Layer 1	**Layer 2**	**Layer 3**	**Layer 4**	**Layer 5**
L_{style_g}	42 s	41 s	43 s	45	47
L_{style_w}	107 s	88 s	87 s	102 s	112 s

Fig. 4. The impact of different style losses on synthesized patterns

combined loss function, where the floral pattern structure is complete, and the texture and colours are clear and bright. The overall visual effect is good, and the synthesis time is short, indicating that the combined loss strategy is reasonable and effective.

Subjective evaluation of experimental results

To evaluate the effectiveness of the proposed method, it was compared with the approaches of Gatys et al. [13], Li and Wand [15], Heitz et al. [20], and Kolkin et al. [19]. Figure 5 shows the images generated by each method.

Gatys et al.'s method utilises Gram matrices to capture the relative relationships between feature maps. However, this approach often produces artefacts when local region feature combinations are inconsistent (e.g., first row, first column, and second row, second column of figure 5). The semantic structure of the synthesised pattern can be incomplete, leading to a scattered floral structure (e.g., fourth row, first column of figure 5). While effective at maintaining overall style, this method has notable deficiencies in handling details, especially in high-frequency complex texture areas.

Li and Wand's method employs Markov Random Fields (MRFs) for texture synthesis, producing images with relatively clear local textures. However, it struggles with colour processing, often resulting in unnatural colours and noise, particularly in brightly coloured patterns (e.g., first row, second column; second row, second column; and fourth row, second column of figure 5). This noise diminishes the visual quality, making the synthesised images appear less smooth and realistic.

Heitz et al.'s method aims to capture complete feature distributions but suffers from detail loss and inaccurate edge handling due to the randomness of projection directions. Consequently, the synthesised textures differ in detail and edges from the original images, particularly in complex patterns (e.g., first row, third column of figure 5).

Kolkin et al.'s method focuses on local feature matching through self-similarity measures. Each local feature vector is matched independently, resulting in consistent local regions but inconsistent feature matching across the image. This leads to incoherent global structures and a lack of consistent global texture control, causing blurred textures (e.g., first row,

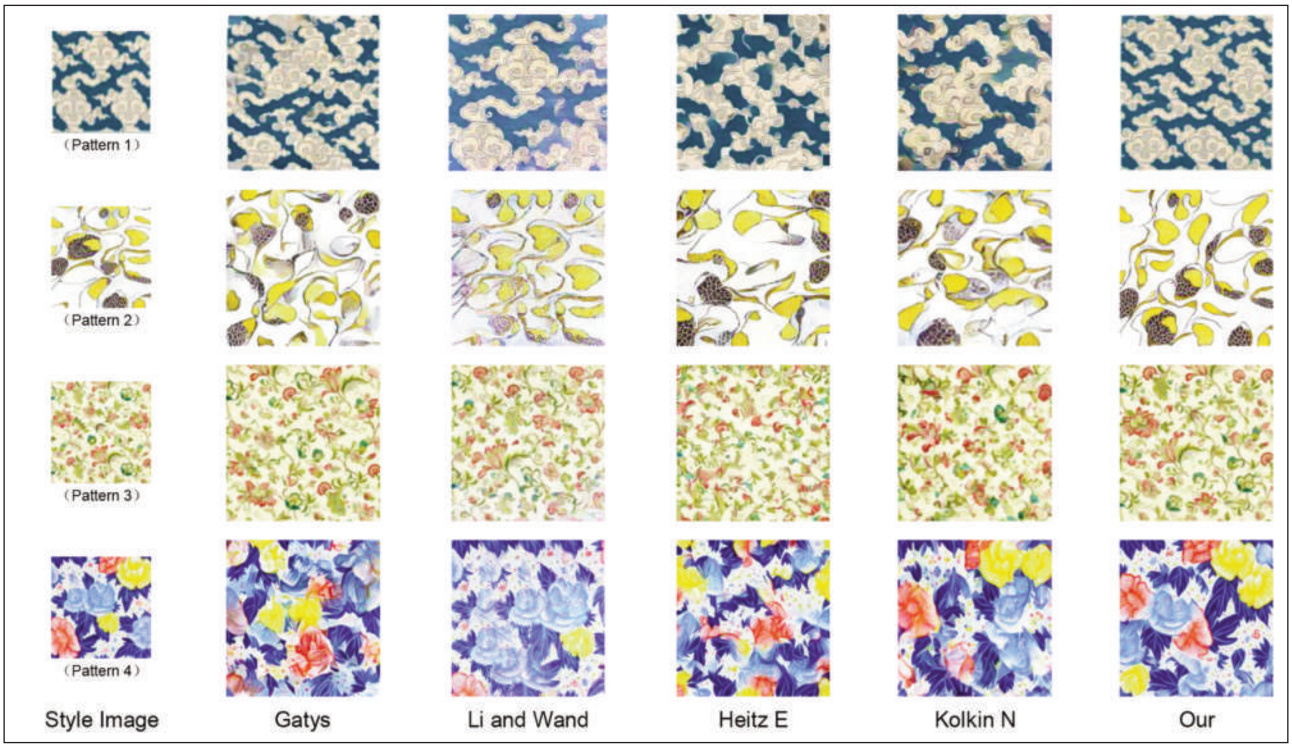

Fig. 5. Examples of fabric patterns generated by different algorithms

fourth column, and second row, fourth column of figure 5), which affects the overall visual effect.

In contrast, the proposed method excels in pattern generation. It employs hierarchical loss to handle different features, resulting in highly distinguishable pattern areas, clear structures, and rich style features. For example, in Pattern 1's high-frequency complex patterns (first row of figure 5), the proposed method produces a more natural synthesis, preserving the details and complexity. In Pattern 2's pattern (second row of figure 5), the targeted reconstruction of low-level and high-level features results in synthesised images with bright overall colours, clear edge details, minimal noise, and no obvious pattern deformation. Overall, the proposed method outperforms other comparative methods in synthesising complex textures and maintaining natural colours, demonstrating its effectiveness in textile pattern synthesis.

Objective Evaluation of Experimental Results

In addition to the subjective assessment of the generated results, an objective quantitative evaluation is also necessary. This paper uses the following metrics for comprehensive evaluation: Structural Similarity (SSIM) [28], Feature Similarity (FSIM) [29], Frechet Inception Distance (FID) [30], and generation efficiency at different resolutions.

Generation Efficiency Performance Evaluation: For the performance evaluation of generation efficiency, this paper compares the pattern generation time of different methods at various resolutions. Table 2 shows the generation time (in seconds) for five methods at four different resolutions. As shown in the table, the proposed method demonstrates higher efficiency at most resolutions, particularly showing a significant time advantage at the 1024×1024 resolution compared to other methods.

The evaluation metrics used provide a comprehensive view of the performance and quality of each method. The Structural Similarity Index (SSIM) is used to measure the similarity between two images, taking into account brightness, contrast, and structural information. The closer the value is to 1, the higher the similarity. The Feature Similarity Index

Table 2

TIME CONSUMPTION FOR TEXTILE PATTERN GENERATION BY DIFFERENT ALGORITHMS

Size	Time				
	Gatys	Li and Wand	Heitz E	Kolkin N	Our
128×128	19	314	86	55	31
256×256	33	693	186	77	48
512×512	78	x	712	118	80
1024×1024	261	x	x	263	242

Note: x indicates that it could not be generated or that it took too long to generate.

Table 3

COMPARISON OF SSIM AND FSIM VALUES OF FABRIC PATTERNS GENERATED BY DIFFERENT ALGORITHMS								
Method	**pattern 1**		**pattern 2**		**pattern 3**		**pattern 4**	
	SSIM	**FSIM**	**SSIM**	**FSIM**	**SSIM**	**FSIM**	**SSIM**	**FSIM**
Gatys	0.053	0.498	0.161	0.42	0.088	0.494	0.037	0.521
Li and Wand	0.950	0.559	0.059	0.443	0.031	0.534	0.043	0.613
Heitz E	0.058	0.519	0.093	0.405	0.091	0.499	0.042	0.505
Kolkin N	0.064	0.533	0.172	0.433	0.086	0.511	**0.065**	0.531
Our	**0.111**	**0.671**	**0.219**	**0.462**	**0.151**	**0.548**	0.054	**0.567**

(FSIM) improves upon SSIM by incorporating gradient and phase consistency, which aligns more closely with human visual perception. The Frechet Inception Distance (FID) evaluates the quality of image generation models, with lower FID values indicating higher quality. FID reflects the similarity between the generated images and real images in terms of statistical features.

Table 3 shows the SSIM and FSIM metrics for various methods across four sets of patterns, while table 4 presents the FID metrics. In these tables, the bold numbers indicate the best values within the same group. In table 3, the proposed method performs excellently overall, especially in the FSIM metric, where it achieves the best values for all patterns. This indicates a significant advantage in preserving pattern features. Additionally, the proposed method obtains the best values in three out of four sets of patterns for the SSIM metric, demonstrating its superior performance in structural similarity. In table 4, the proposed method achieves the lowest FID values in three out of four sets of patterns, and its overall FID value is lower than that of other methods, indicating strong image generation capability. Combining these metrics with generation efficiency, the comprehensive analysis shows that the proposed method has a significant advantage in preserving pattern features and generating high-quality images. This proves its effectiveness and reliability in the task of textile pattern generation.

Table 4

COMPARISON OF FID VALUES OF FABRIC PATTERNS GENERATED BY DIFFERENT ALGORITHMS				
Method	**FID**			
	pattern 1	**pattern 2**	**pattern 3**	**pattern 4**
Gatys	606.743	957.293	254.106	702.38
Li and Wand	**137.743**	1052.671	426.433	343.099
Heitz E	220.682	1109.606	1222.413	942.944
Kolkin N	360.702	988.794	482.411	374.394
Our	374.595	**607.989**	**228.73**	**291.368**

Ablation experiment

To verify the effectiveness of the attention feature module, a series of ablation experiments were conducted. As depicted in figure 6, figure 6,*a* displays two input style patterns: one is a traditional Chinese cloud pattern textile, and the other is a modern colourful fabric texture pattern. Figure 6,*b* presents the generated patterns without the channel-spatial attention module, while Figure 6,*c* shows the results after adding the channel-spatial attention module. Other parameters were kept constant throughout the experiments.

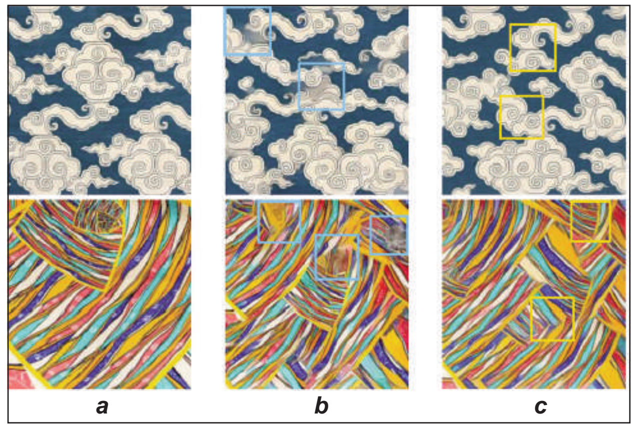

Fig. 6. Attention feature ablation experiment: *a* – input style patterns; *b* – generated patterns without the channel-spatial attention module; *c* – results after adding the channel-spatial attention module

From the experimental results, it is evident that the cloud pattern textile in figure 6,*b* exhibits artefacts at the overlapping cloud elements, and the transitions between pattern elements appear unnatural.

Similarly, in the colourful fabric texture pattern of figure 6, *b*, there are artefacts at the junctions of texture elements, with some areas showing colour overflow. In contrast, the generated patterns in figure 6,*c* show significant improvements in these aspects. The transitions between elements are more natural, and the detail and overall visual quality of the patterns are enhanced. Therefore, the attention feature module has a crucial impact on the generation effect of the algorithm and is an indispensable part of the algorithm.

CONCLUSION AND FUTURE WORK

This study proposes a fast multiscale synthesis algorithm for textile patterns based on neural networks. By combining low-level and high-level feature losses, the algorithm meticulously processes pattern features while preserving their semantic structure, achieving comprehensive style transfer. The convolutional attention feature enhancement module refines features, reduces artefacts, and improves visual quality, while the multiscale optimisation module enhances image texture and layering. Experimental results indicate that this method outperforms existing methods in terms of visual effect and scalability of pattern synthesis. By extracting and applying the style features of inspirational patterns, this method effectively helps designers focus on creativity and concept development, improving design efficiency and promoting the intelligent development of textile design and production. However, this study still has room for improvement. The generation time for high-resolution patterns needs optimisation, and there is a lack of interactive design features. Future research will explore the application of different attention mechanisms and interactive design modules, as well as improve the efficiency of high-resolution pattern generation.

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Impact of pattern lines and technological features on the behaviour of vamp-over-quarter footwear type

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ABSTRACT – REZUMAT

Impact of pattern lines and technological features on the behaviour of vamp-over-quarter footwear type

This article aims to demonstrate how the positioning of the seam line between the vamp and quarter and the number of stitches affect the joint strength and overall performance of the product during walking. The configuration of analysis conditions and constraints was conducted using ANSYSTM. The gait biomechanics were considered to establish the load model, including the distribution of forces, their magnitudes, and constraints. The analysis focused on the three phases of gait: heel strike, mid-stance, and push-off, evaluating three key parameters: directional displacement, Von Mises stress, and elastic deformation. The study emphasises how directional displacement, stress distribution, and elastic deformation change based on the gait phase and the materials used in the construction of the selected footwear type. Using a two-stitch seam to join the components promotes directional displacements and reduces stress/tension compared to a single-stitch seam. Positioning the seam line between the vamp and quarters along the toe line increases stress/tension in the front section of the shoe. The analysis was validated by comparing simulation results with average plantar pressures obtained from a biomechanical assessment of plantar pressure distribution.

Keywords: *gait biomechanics, directional displacement, von mises stress, elastic deformation, plantar pressure distribution*

Impactul liniilor de model și al caracteristicilor tehnologice asupra comportamentului încălțămintei de tip căpută peste carâmb

Acest articol își propune să demonstreze modul în care poziționarea liniei de cusătură dintre căpută și carâmb, împreună cu numărul de tigheluri, afectează rezistența îmbinării și performanța generală a produsului în timpul mersului. Configurarea condițiilor de analiză, precum și a constrângerilor a fost realizată utilizând ANSYSTM. Biomecanica mersului a fost luată în considerare pentru a stabili modelul de încărcare, inclusiv distribuția forțelor, magnitudinea acestora și constrângerile. Analiza s-a concentrat pe cele trei faze ale mersului: impact, reazem și propulsie, evaluând trei parametri cheie: deplasarea direcțională, tensiunea Von Mises și deformarea elastică. Studiul subliniază modul în care deplasarea direcțională, distribuția tensiunii și deformarea elastică se modifică în funcție de faza mersului și de materialele utilizate în construcția tipului de încălțăminte selectat. Utilizarea unui tighel dublu pentru a îmbina reperele, favorizează deplasările direcționale și reduce tensiunea în comparație cu un singur tighel. Poziționarea liniei de cusătură între căpută și carâmbi de-a lungul liniei degetelor crește tensiunea în zona anterioară a încălțămintei. Analiza a fost validată prin compararea rezultatelor simulării cu cele ale presiunilor plantare medii obținute din evaluarea biomecanică a mersului.

Cuvinte-cheie*: biomecanica mersului, deplasare direcțională, tensiune von mises, deformare elastică, distribuția presiunii plantare*

INTRODUCTION

The constructive type of footwear, vamp-over-quarter, called Oxford, involves seaming the entire length of the anterior contour of the quarter. This ensures a more uniform stretching during space forming in both longitudinal and transversal directions, and the displacement of the pieces in the longitudinal direction is smaller than in the case of the quarter-over-vamp construction. Taking into account the deformability of the prefabricated in spatial forming, the opening point of the cap should be displaced towards the instep. The joint area between the toe cap and the quarters is subject to high stresses during walking. For this reason, it is recommended to add a reinforcing notch to increase the strength of the joint in the area of repeated bending [1–3].

Finite element modelling has emerged as a powerful tool for gaining a deeper understanding of foot and footwear biomechanics, as well as for optimising footwear designs. In recent years, several researchers have identified key challenges and research gaps that must be addressed to develop more realistic and precise models for both clinical and industrial purposes [4]. While most existing foot-shoe FE analyses have been conducted with certain simplifications and assumptions, they have significantly contributed to understanding the mechanical behaviour of the foot in both casual and athletic footwear. However, further simulations continue to face multiple obstacles, including obtaining reliable data for geometric reconstruction, balancing detailed accuracy with computational efficiency, accurately representing material properties, applying realistic boundary and loading conditions, and ensuring comprehensive model validation [5–8]. Given the current research gaps in areas related to footwear design, the authors of this study have aimed to validate the FE model both internally and externally.

Biomechanical assessments of how footwear characteristics affect foot parameters and the interaction between the foot and shoe can be valuable for preventing injuries and optimising footwear design [9, 10]. Laboratory-based methods like 3D motion capture analysis and in-shoe plantar pressure monitoring can provide useful insights. However, due to technological limitations, precise mechanical changes, such as the distribution of internal stress and strain within foot structures and joint contact pressures, remain unmeasurable. In response to this challenge, researchers have increasingly turned to computational approaches, such as finite element (FE) analysis, for more detailed investigations. FE analysis allows for the modelling of complex geometries, varied material properties, and intricate boundary and loading conditions [11–13].

METHODOLOGY

To evaluate how the line position and the number of stitches influence the gait behaviour of the footwear, a classic vamp-over-quarter type of footwear was chosen, whose upper assembly includes the following components: vamp, quarters, tongue and counter.

The shoe was modelled in the DELCAMTM Shoe Maker application, using the last designed based on the average representative foot specific to the group of subjects analysed in a previous anthropometric study undertaken by the authors [14].

To obtain the virtual model, the following steps were performed:

- import the last previously obtained;
- drawing the baselines, checking the position of the toe line (point C), determining the height of the quarter at the back, drawing the upper line of the quarter, marking the point of the instep and drawing the auxiliary line of the instep;
- drawing the pattern lines according to the rules for the design of Oxford-type shoes;
- creating the components (vamp, tongue, quarters, counter), adding the details (stitching, laces) and the sole.

Three variations of the Oxford shoe were designed by changing the position of the separation line between the upper and the toe: the topline positioned on the toe line; the line of the vamp positioned 10 mm towards the tip; the vamp line positioned at 10 mm towards the instep (figure 1).

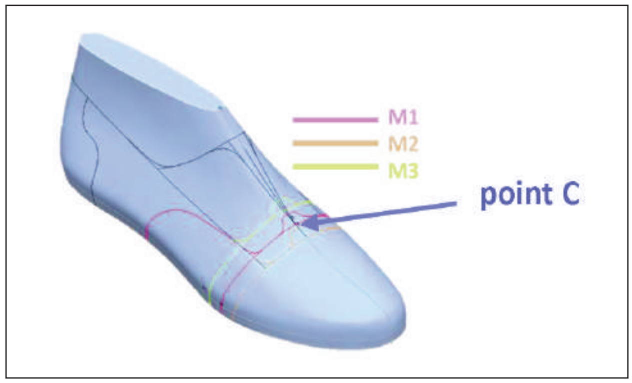


Fig. 1. Variations of the Oxford shoe

For each model, two other model variants were developed, with one and two stitches. The width of the overlap area between the vamp and the quarters and the quarters and the counter is 8 mm. The distance between the eyelets is 8 mm. To recognise the geometrical elements and perform the finite element analysis, each geometrical feature was processed individually using the tools provided by the Space Claim program integrated in the ***ANSYSTM*** suite. The foot was reconstructed based on the imported last in *.stl format. The upper set imported in *.iges format and opened in the Space Claim application is presented as a set of surfaces. Each part consists of four surfaces. To avoid errors during simulation and to simplify the model, surfaces that do not influence the structure of the upper assembly have been removed. The remaining surfaces were assigned a thickness of 2 mm. The original model was provided with laces, but it was decided to remove them because of the errors that can be introduced by them. The sole, the structure of which the insole is integrated, also imported in *.iges format, was transformed into a solid using the tools in the Repair menu.

The whole foot and sole assembly has been positioned on a parallelepiped support built directly in the Space Claim application.

The result of this step is a highly accurate model consisting of three solids – simplified foot, sole and support, and a group of surfaces, representing the component parts of the upper assembly (figure 2).

Determining the properties of materials

The values for the Young's modulus and Poisson's ratio specific for the foot, upper assembly (overlap zone, lacing zone), bottom assembly and support are given in table 1.

In the case of the foot, a basic structure has been chosen, for which the properties of the muscular and skeletal system, cartilages and joints are neglected. For the characterisation of the sole, a material with properties and characteristics specific to rubber was chosen [15, 16]. Textile materials play a crucial role in footwear, serving as key components in uppers, linings,

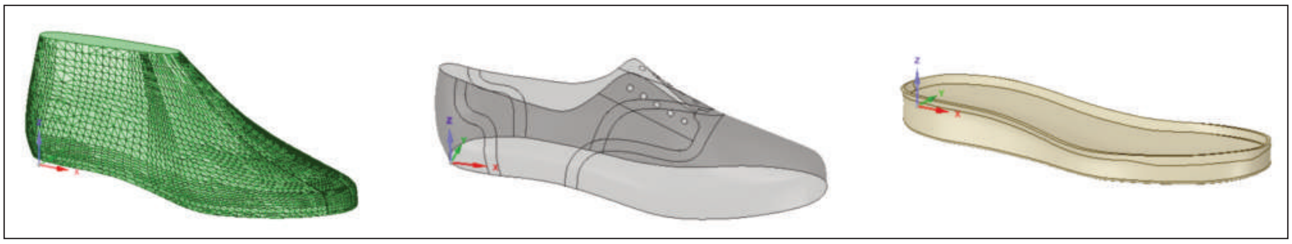


Fig. 2. Editing and preparing 3D components for simulation

Table 1

PROPERTIES OF THE MATERIALS USED IN THE ANALYSIS			
	Young's modulus (MPa)	Poisson's ratio	Thickness (mm)
Foot	4.47	0.45	-
Knitted + cowhide lining (uppers)	55.9	1.10	1.9
Knitted + cowhide lining, 8 mm overlap, single stitch (uppers)	11.2	1.01	2.4
Knitted + cowhide lining, 8 mm overlap, double stitch (uppers)	14.5	1.00	2.4
Knitted + cowhide lining, perforation spacing of 8 mm, with staples (uppers)	55.9	0.46	1.9
Rubber (sole)	1000	0.42	-
Concrete (support)	90000	0.18	-

and insoles. They offer breathability, flexibility, and comfort while incorporating advanced options such as mesh, canvas, and engineered fabrics to optimise performance and aesthetics [17]. Their lightweight and sustainable nature further enhances functionality and design versatility [18–20], making them indispensable in modern footwear engineering. In contemporary footwear production, the integration of textile materials with leather has become increasingly prevalent. This study focuses on a simplified model combining knitted material with cowhide leather for analysis and evaluation. The upper assembly was defined as bovine leather on the outside and Belgian overknit on the inside. The overlap areas joined by stitching and the lacing areas with perforations were described according to the data obtained from the study of the mechanical behaviour of the materials. The entire shoe-foot assembly stands on a concrete support.

Setting up the analysis conditions. Making connections and setting model loading conditions

The behaviour of the three model variants was analysed in the Static Structural module. To perform the finite element analysis, each geometric entity was assigned materials with properties defined in the previous step. Model discretisation was performed using the The traedrons method. The line grid was created using a coarse finite element size and with an average adjustment of the node positions, resulting in a grid with 133214 nodes and 78408 elements (figure 3). A direct connection was created between all elements with a tolerance of 0.91 mm.

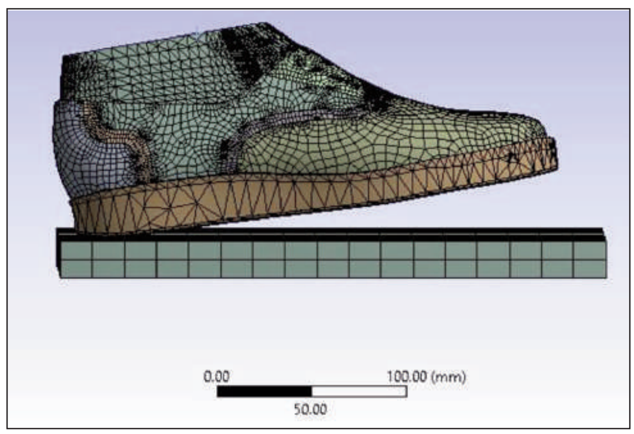


Fig. 3. Defining a line grid on the surface of the 3D model (mesh)

To define the loading model, the distribution of forces and their values, the restrictions imposed by gait biomechanics were taken into account.

Three gait phases were analysed: heel strike, mid-stance and push-off. In the mid-stance phase, the foot is in contact with the ground plane over the entire plantar surface. In the heel strike and push-off phases, the foot touches the ground plane partially and is inclined to the ground plane by –7 and 7 degrees, respectively (figure 4).

It was considered that in the heel strike and push-off phases, the body acts with a force equal to 1.2*G. Taking into account that the average body mass specific to the group of subjects obtained from the biomechanical study conducted by the authors [14] is 52 kg, a force of 612 N was applied. Since the

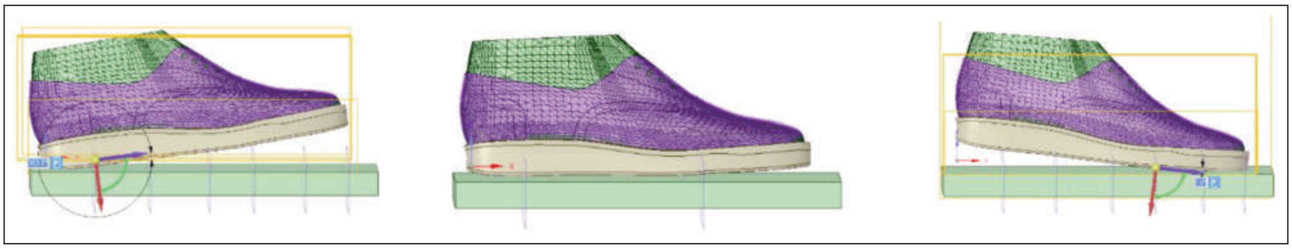


Fig. 4. Representation of foot positions in heel strike, support and push-off phases

analysis is performed on one leg, the distributed weight is equal to G/2, i.e. the applied force is 255 N. The forces were applied to the dorsal surface of the foot in a vertical downward direction. Displacement of the footwear-foot assembly was allowed in the Z-direction, while the support was considered fixed. The analysis time was limited to one second.

Configuring analysis parameters

Directional deformation of Z-directional component, stress distribution, and elastic deformation were evaluated to examine the behaviour of three previously modelled variants. The changes occurring in the footwear during the three gait phases for one second under the influence of the weight force were recorded and analysed.

The directional deflection highlights the displacements of the model under the influence of the determined forces. The Von Mises stresses help to determine the efficiency of the materials under analysis and the distribution of pressures in them, while the elastic deformation is intended to define the limit to which the model returns to its original shape after load removal.

RESULTS

Solving the finite element model. Analysis results

Once the displacements and directional deformations have been calculated, the application displays the values of the tensions and moments acting on the footwear due to the interaction with the foot and the support surface.

The results for the directional deformation field, stress field distribution and elastic deformation obtained from the analysis were centralised, 54 representations being obtained. The authors have selected 3 relevant examples for the propulsion phase and presented them in figure 5.

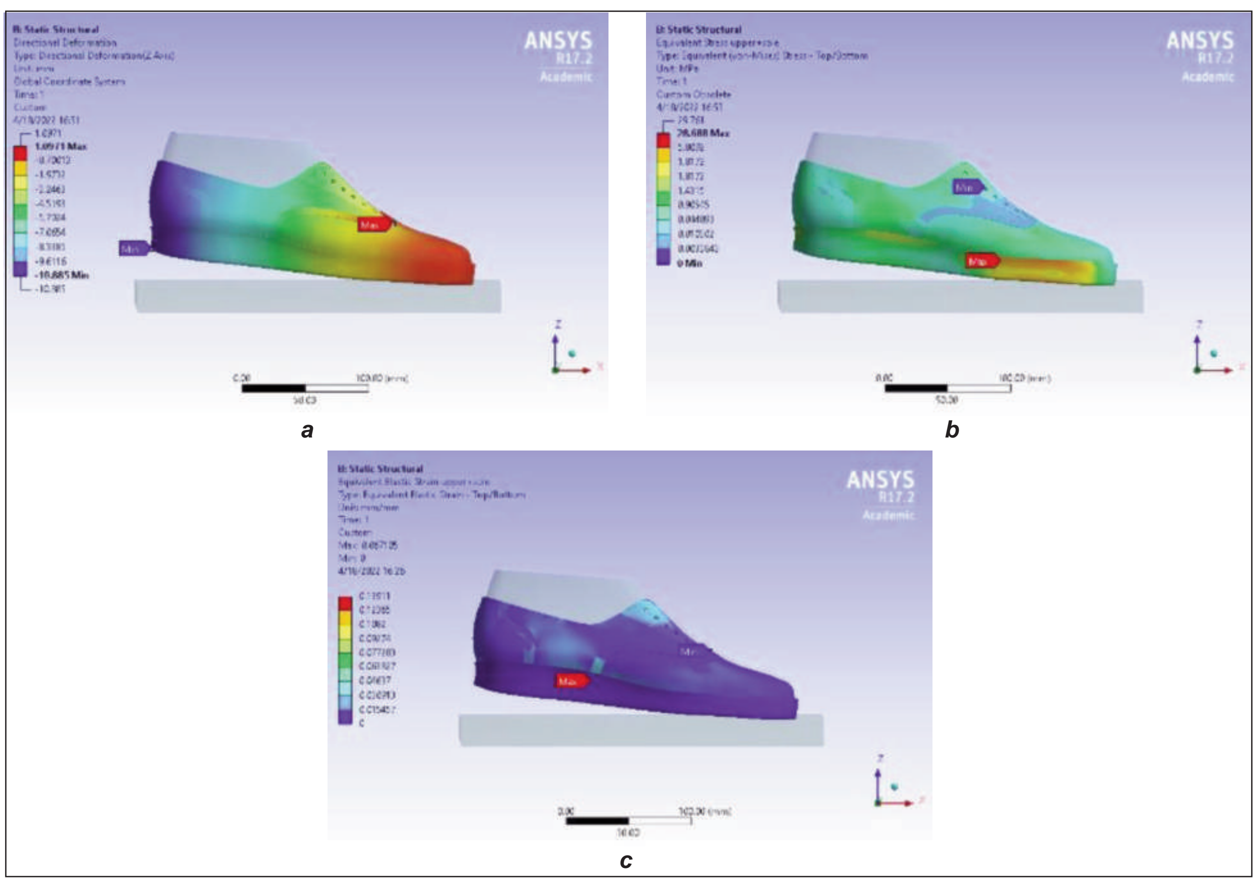


Fig. 5. Representation of: *a* – the directional deformation field; *b* – stress field distribution; *c* – elastic deformation obtained in propulsion phase

The recorded values are accompanied by images containing a set of colours ranging from blue (low values) to red (high values). This colour coding, accompanied by the numerical values obtained, highlights areas of high pressure and deformation in the patterns, which affect both the footwear and the foot during gait.

The analysis parameter with Z-axis directional deformation has the highest values in the push-off and heel strike phases, when the foot is subjected to significant forces. This distribution is similar for all models analysed.

The chromaticity maps suggest that the maximum deformation values in the Z-direction for all models are found in the upper assembly, and their distribution varies with the phase of walking. In the heel strike phase, the deformations are higher in the heel area (quarter and counter) and decrease in the vamp area. The overlap area between the vamp and the quarters shows an average deformation for all the model variants analysed. In the mid-stance phase, according to the colour maps, the magnitude of the deformation is smaller and its distribution on the shoe surface is more uniform. In the push-off phase, when the efforts are transferred to the toe area, both the vamp and the overlap between the vamp and the quarters are exposed to larger deformations.

Figure 6 graphically shows the maximum values of the directional deformation fields, Von Mises equivalent efforts and elastic deformations for the three model variants in each gait phase.

In the heel strike phase, the differences from one model to another are larger, and the maximum deformation in the Z-axis direction is shown by model M2 (0.2858, 0.2697 mm), followed by M1 (0.2460, 0.2321 mm) and M3 (0.2210, 0.2210 mm). In the support phase, the maximum value is the model M3 (0.0195, 0.0193 mm), followed by M2 (0.0194, 0.0193 mm) and M1 (0.0193, 0.0192 mm), the differences between the values being almost insignificant. The maximum value in the push-off phase is M2 (1.0971, 1.0764 mm), followed by M1 (0.4541, 0.4548 mm) and M3 (0.3493, 0.3496 mm), respectively. The versions of the model joined by a double stitch show less deformation compared to the single stitch pattern versions.

Analysis of the stress field reveals that higher pressures occur in the footwear product in the push-off phase (29.761, 29.759, 28.688, 28.684, 28.528, 28.525 MPa), followed by the heel strike phase, with a reduction of about 80% (5.974, 5.951, 6.559, 6.538, 5.475, 5.461 MPa), and the support phase, respectively, with a 94% decrease compared to the push-off phase (1.903, 1.902, 2.028, 2.029, 2.251, 2.249 MPa). Such a distribution is due to the high deformation of the footwear occurring in the area of repeated bending in the metatarsophalangeal joint of the foot in the push-off phase, respectively, a more uniform distribution in the mid-stance phase, a situation

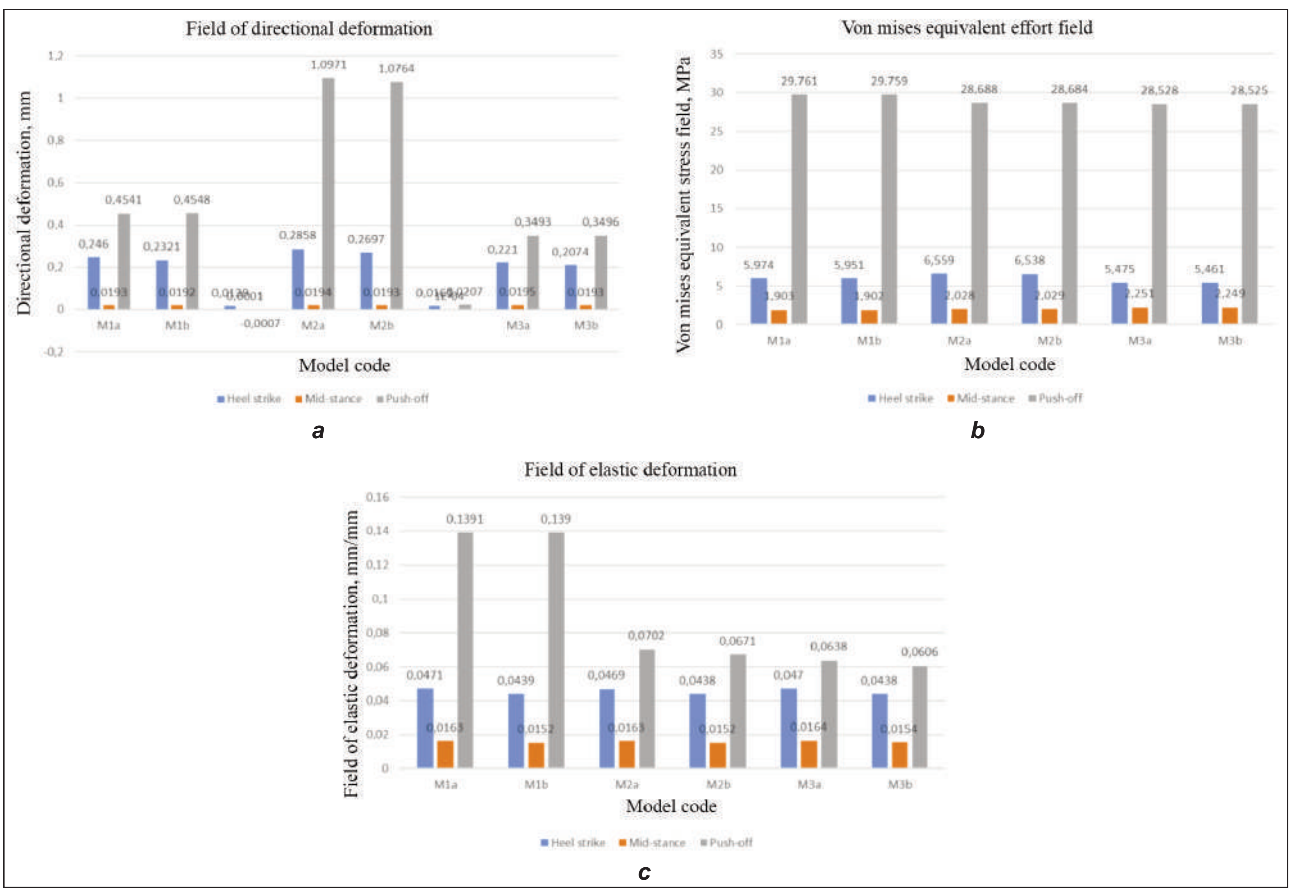


Fig. 6. Representation of: *a* – Z-axis directional deformation field for the vamp-over-quarter footwear; *b* – Von Mises equivalent force field for the vamp-over-quarter footwear; *c* – elastic deformation field for the vamp-over-quarter footwear

confirmed in the literature [19]. Analysing this parameter from the perspective of each model, higher values are observed for M1 in the push-off phase. This highlights that the positioning of the sectional line between the vamp and the quarter on the toe line leads to an increase in the pressures in the anterior area of the shoe. M2 and M3 show Von Mises stress values about 4% lower compared to M1.

The distribution of the elastic deformation varies in different areas depending on the phases of walking, model lines and technological particularities (in this case, the number of stitches). Maximum elastic deformation occurs in the push-off phase. In the heel strike and mid-stance phases, the values of this parameter decrease by about 66% and 88%, respectively. Similar to the distribution of values for the stress field parameter, also in the case of elastic deformation higher values occur in the M1 model (0.1391, 0.1390, 0.0163, 0. 0152, 0.0471, 0.0439 mm/mm), followed by model M2 (0.0702, 0.0671, 0.0163, 0.0152, 0.0469, 0.0438 mm/mm) and model M3 (0.0638, 0.0606, 0.0164, 0.0154, 0.047, 0.0438 mm/mm). Analysis of the chromaticity maps shows that the values of elastic deformation are very low in the joint area between the vamp and the quarter. Seam with two stitches leads to a decrease of about 5% of the elastic deformation compared to one stitch.

Validation of the load model

The validation of this analysis was carried out according to the methodology presented in a previous study [21], comparing the simulation values with the representative average plantar pressures obtained from the biomechanical study [22].

The maximum plantar surface pressure values and corresponding images for each zone are centralised in table 2.

By graphically showing the values in figure 7, a distribution model of the simulated maximum pressure values can be observed, which is very similar to the distribution of the experimentally obtained values.

The graphical representation of the values (figure 7) highlights that the results obtained to validate the data corresponding to the loading model (M2 being selected for this study) follow the same trend of plantar pressure distribution. Very close values were obtained in the case of First metatarsal (Z3), Second Metatarsal (Z4), Fourth Metatarsal (Z6), Lateral Heel (Z10). In the cases of First Toe (Z1), Third Metatarsal (Z5) and Fifth Metatarsal (Z6), the values obtained by simulation present larger differences compared to the experimental values. The registration of such differences is explained by the simplicity of the loading model, certain forces being ignored, as well as by the use of a simplified foot shape.

CONCLUSIONS

The objective of this study was to analyse how the model lines and the technological characteristics influence the behaviour of the Oxford-type shoe by simulating the biomechanical conditions of normal gait.

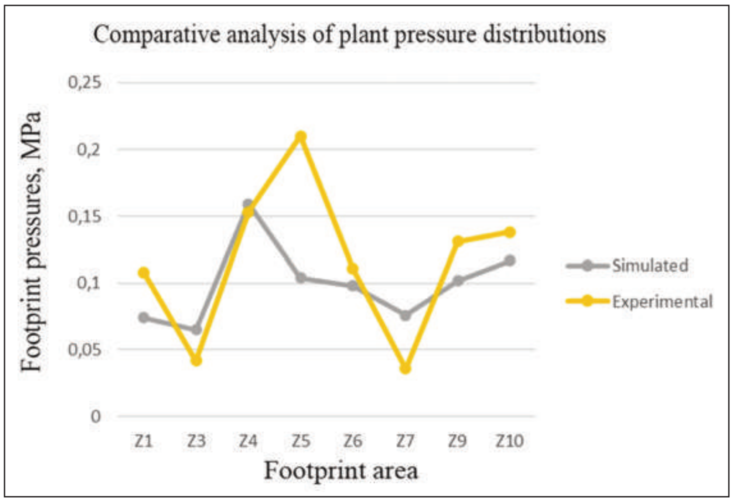
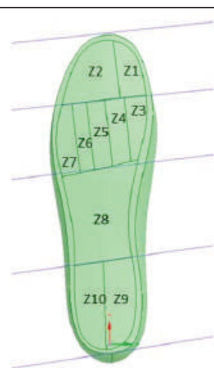


Fig. 7. Comparative analysis of simulated and experimental plantar pressure distributions

Table 2

SIMULATED AND EXPERIMENTAL MAXIMUM PLANTAR PRESSURES			
Area		Plantar pressures (MPa)	
		Simulated	Experimental
Z1 – First Toe		0.074	0.108
Z3 – First metatarsal		0.065	0.042
Z4 – Second Metatarsal		0.159	0.153
Z5 – Third Metatarsal		0.104	0.210
Z6 – Fourth Metatarsal		0.098	0.111
Z7 – Fifth Metatarsal		0.076	0.036
Z9 – Medial Heel		0.102	0.131
Z10 – Lateral Heel		0.117	0.138

The position of the sectioning line between the vamp and the quarters and the number of stitches that form the seam joint were chosen as the variables.

The footwear models were designed using the DELCAMTM Shoe Maker 3D application according to the specific design rules for the vamp-over-quarter construction. The simplified foot model was reconstructed using a last derived through modelling, based on the average dimensions of a representative sample from the subject group.

Using ***ANSYSTM,*** the material definition, 3D model editing for import into the simulation application, analysis conditions and constraints configuration were performed.

The gait biomechanics were taken into account to define the loading model, the distribution of forces, their values and constraints. The analysis considered the three phases of gait: heel strike, mid-stance and push-off, evaluating three analysis parameters, namely directional deformation, Von Mises forces and elastic deformation.

The study highlights how the directional deformation, the stress field and the elastic deformation vary depending on the gait phase and the types of materials used in the structure of the sports footwear. Joining the components with a two-stitch seam favours directional deformations and lower stresses/tensions compared to a single-stitch seam.

The positioning of the section line between the vamp and the quarters on the toe line leads to an increase in stresses/tensions in the anterior area of the shoe. Positioning the section line between the vamp and the quarter on the toe line leads to an increase in the efforts in the forefoot area. Shifting the line 10 mm towards the toe or instep results in a decrease in effort of approximately 4% compared to a shoe model with the section line between the vamp and the quarter positioned on the toe line.

The analysis was validated by comparing the simulation values with representative mean plantar pressures obtained from the biomechanical study of plantar pressure distribution.

ACKNOWLEDGEMENT

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Impact of management practices on employees' safety performance. Highlighting safety as a sustainable development goal in textile industry

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ABSTRACT – REZUMAT

Impact of management practices on employees' safety performance. Highlighting safety as a sustainable development goal in textile industry

Over time, thousands of employees were killed due to bad infrastructure, a poor emergency system and a weak health and safety system in the textile industry of Pakistan. Management needs to identify the workplace hazards to improve the employees' performance. The current study was conducted to determine the impact of management practices on employees' safety performance in Pakistan's textile industry. For this purpose, primary data was collected from the managerial staff of the textile sector. Smart PLS and SPSS 23 were used for data analysis. A total of 180 questionnaires were sent to the respondents, out of which 165 questionnaires were received back. Organisational health and safety is considered a management issue; in previous studies, this issue has not been explored by scholars. Organisational health and safety issue is also considered a general management issue; it continues to be overlooked by scholars in the management field. The findings show that management commitment, promotion of employees, and safety training affect the employees' safety performance. Safety knowledge and safety motivation mediate the relationship between Management practices and employees' safety performance. Meanwhile, institutional pressure moderates the relationship between HR practices and safety knowledge and safety motivation significantly. The findings of this study provide useful insights for managers in designing the mechanism by which workplace safety can be enhanced.

Keywords: *management commitment, safety training, safety motivation, safety knowledge, employee's safety performance, institutional pressure*

Impactul practicilor de management asupra performanței în materie de siguranță a angajaților. Evidențierea siguranței ca obiectiv de dezvoltare sustenabilă în industria textilă

De-a lungul timpului, mii de angajați au fost uciși din cauza infrastructurii deficitare, a sistemului de urgență deficitar și a sistemului de sănătate și securitate subdezvoltat în industria textilă din Pakistan. Este esențial ca managementul să identifice pericolele la locul de muncă pentru a îmbunătăți performanța angajaților. Studiul actual a fost realizat pentru a determina impactul practicilor de management asupra performanței în materie de siguranță a angajaților în industria textilă din Pakistan. În acest scop, au fost colectate date primare de la personalul managerial din sectorul textil. Pentru analiza datelor au fost utilizate metodele Smart PLS și SPSS 23. Un total de 180 de chestionare au fost trimise respondenților, dintre care 165 de chestionare au fost primite înapoi completate. Sănătatea și securitatea organizațională sunt considerate o problemă de management, însă în studiile anterioare această problemă nu este suficient explorată de către cercetători. Problema sănătății și securității organizaționale este, de asemenea, considerată o problemă generală de management, care însă continuă să fie trecută cu vederea de către cercetătorii din domeniul managementului. Rezultatele empirice arată că angajamentul managementului, promovarea angajaților și instruirea în materie de siguranță afectează performanța în materie de siguranță a angajaților. Cunoștințele în materie de siguranță și motivația în materie de siguranță mediază relația dintre practicile de management și performanța în materie de siguranță a angajaților. Între timp, presiunea instituțională moderează semnificativ relația dintre practicile de resurse umane și cunoștințele în materie de siguranță și motivația în materie de siguranță. Rezultatele acestui studiu oferă perspective utile managerilor în proiectarea mecanismului prin care poate fi îmbunătățită siguranța la locul de muncă.

Cuvinte cheie: *angajamentul conducerii, instruire în domeniul siguranței, motivație în domeniul siguranței, cunoștințe despre siguranță, performanța angajaților în domeniul siguranței, presiune instituțională*

INTRODUCTION

Safety at work and safe work are important for improved production and higher employee productivity, and so the promotion and maintenance of healthy work is a complementary feature of industrial growth [1, 2]. The underlying sources of hazards in their products may produce unsafe work and work environments. The International Labour Organisation and the World Health Organisation define workplace safety as "Occupational health should be a goal at the maintenance and promotion of the topmost quality of mental, physical and social well-being of employees in all kinds of work". Occupational health and safety is a multidisciplinary field that includes occupational nursing, industrial hygiene, epidemiology, toxicology and engineering [3].

Work health and safety practices help improve employees' productivity at the workplace and reduce injuries at work by providing progressive feedback on the workforce's performance [4]. The International Labour Organisation has said that an injury in the workplace impacts an employee's life. Safety is a rather broad term which refers to the prevention of accidents that cause harm to humans [5]. The definition of safety is therefore broad in that it can extend from accidents or events involving only mild physical injury, such as a buried or a slight cut, to serious injuries requiring heavy medical treatment or that could lead to death. Furthermore, with an emphasis on reducing injury, safety often requires efforts to understand and avoid new injuries. Therefore, work on protection also often aims at strengthening the employee safety behaviour [6]. Employment risks have led to very low malfunctions, workplace infections and adverse effects on textiles.

The textile industry has various hazard categories, such as physical, biochemical, chemical and ergonomic risks. These factors contribute to poor working conditions, reports of deaths and harmful diseases [7, 8]. The textile industry has several diseases, including lung cancer, TB, kidney stones and ENT (ear, nose and throat) [9]. The Pakistani industries need uncompromising improvement of the implementation of workplace health and safety practices because they did not take this valuable parameter as much account as they needed [10, 11]. Pakistan has far more work-related deaths than any democratic nation [12].

Organisations depend today on information as their main resource of power. Because of its great significance, organisations have increasingly moved to knowledge organisations. As this change attracted numerous scholars in various fields to explore the notion of information, an infinite variety of knowledge definitions varied about the methods they addressed. This paper aims to examine how management activities affect safety in the workplace in Pakistan's textile industry. In particular, it explores the underlying mechanisms for relations between management's and safety performance by examining the influence of critical practices on employee safety behaviour: (i) management safety commitment; (ii) training of safety; (iii) employee involvement in safety encouragement; (iv) pay method [13, 14].

Structure of the paper

The remainder of this paper is structured as follows: 2nd reviews the relevant literature on management practices, institutional pressure, safety knowledge, safety motivation, and their impact on safety performance. 3rd section discusses the research methodology, including data collection and analysis techniques. 4th section presents the key findings and discusses their implications for workplace safety. Finally, the 5th section concludes the paper, highlighting key takeaways and suggesting directions for future research.

Problem statement

The hazards in Pakistan's textile industry include swarming conditions, uncovered machinery at work, unrefined and dangerous electrical units, unavailability or breakage of a few or no terminated dousers, no rehearsals of terminate ever performed, the leaders and employees are not prepared to comprehend problems of well-being and security, stairs and floors used as capacities; in crises doors remains closed; production units not open like offices, limited path for firefighters to enter in units and provide safety. literature has shown that bad physical and psychosocial working environments can cause person health and well-being to deteriorate [15]. Many of these findings relate to workplace problems with terms such as stress-induced disease. However, the impact that working environments have on workers' welfare remains an area of little focus within occupational science.

Considering today's organisations' comprehensive safety issues still faced, more research in this field is urgently needed. Early security analysis has concentrated principally on errors and employees involved in a faulty procedure, but over recent years, attention has shifted from employee-level accident explanation and accident to corporate explanations [16].

Literature and current observations suggest that health and safety practices are still not properly implemented in the textile sector of Pakistan. However, the textile sector requires to implement the implementation of health and safety practices. In the textile sector, no compliance department is properly working as most of the organisations have an HR department which are going to performs the HR department see all the functions of the compliance department, but there is no separate compliance department to implement the health and safety practices. If an organisation have a compliance department but it is not working properly. On the other side, various national and international institutions exert pressure on organisations to implement health and safety practices to improve their safety performance. This study investigates the impact of HR practices on improving employees' safety performance through the mediating role of safety knowledge and safety motivation. Further explore whether Intuitional pressure makes the impact of proximal on safety performance and employees' performance more significant or not.

Research gap

There is scarce research in Pakistani organisations on the administration of the issue of occupational health and safety. OHS is a human resources management concern, even though it is also seen as a general management issue; researchers in management continue to ignore it. The goal of this study is to define the fundamental processes that connect management with safety outcomes by examining the impact of critical management practices on employee safety behaviour. Workers' work safety and health have improved and are comparatively satisfactory in the developed world, while work health remains low and poorly addressed in the list of national priorities in developing countries [17]. The current research was intended to evaluate knowledge and management strategies for the textile industry about safety, security, and the performance of employees and relevant factors responsible for it. This also applies to Pakistan, which is an underdeveloped nation in Asia.

LITERATURE REVIEW

Scholars conceptualise safety output as individual behaviour output at the workplace, which contributes to the safety of an individual as well as to that of their employees as a whole, rather than as an organisational measure for safety results that concentrate on injury or accident numbers per year, following [13, 16, 18]. It is necessary to differentiate ethical behaviour from such activity results, since each behaviour may require various relationships with both distal and proximal determinants [18]. This conceptualisation gives the researcher an accurate and observable criterion in comparison with crashes or deaths, even with a low base rate and biased distributions [19].

There have been several different conceptual models for safety performance created throughout time. "Actions or behaviours that people display in practically all occupations to improve the health and safety of employees, customers, the general public, and the environment" were characterised as "safety performance" [20].

Using PPE, reducing risk at work, communicating dangers and accidents to employees, and exercising employee rights and obligations are all part of this notion. Burke et al. [20] discovered that these variables are significantly associated and that, under certain circumstances, it is reasonable to use a composite safety performance score.

In other words, there are several ways to think about safety performance [16, 21]. Safety compliance refers to generally mandated behaviours such as "adhering to safety procedures and carrying out work in a safe manner," while safety participation refers to safety behaviours beyond the employee's formal role, such as "helping coworkers, promoting the safety program within the workplace, demonstrating initiative, and putting effort into impairing the safety of the workplace" [16]. The authors make a difference between safety compliance and safety involvement in this study.

The link between management and safety performance

Management consequences may be investigated in two directions regarding OHS results. The first strategy is focused on a management framework perspective, which takes into account the total impact of the activities (Bowen and Ostroff 2004). For a structure solution, staff are supposed rather than human activities to be subject to management schemes [22, 23]. Therefore, the results of such a strategy will only show the implications of aggregate management activities, not individual management practices, as a group. A second methodology is, however, focused on assessing the impact of a single HR or general management procedure rather than the total management systems configuration or consolidation [24]. Recruitment and evaluation have been identified, for example, through recruiting people with particular personalities, physical traits and job experience, and a strong level of safety awareness [24–26]. We take this method as it promotes research and thus awareness of the importance of various management activities in the management of protection.

Neal and Griffin [21] occupational safety model to create a model of processes whereby management activities affect safety efficiency. This model is based on the theory of success, Campbell et al. [27], which describes three proximal determinants of each performance: awareness, abilities and motivation.

There's also evidence in the model that implies distal antecedents of success, such as personality or experience or management techniques, can only affect performance if they raise the proximal ones first. These findings imply that factors at the individual (personality and life experience) and organisational levels (safety environment) have a direct impact on worker knowledge and motivation, which has a knock-on effect on workplace safety outcomes [16]. Individual variations and the safety environment serve as the distant antecedents of safety performance, but knowledge and motivation are the proximal determinants. Neal et al. amended the paradigm to incorporate management practices since the emphasis of this article is on the role of particular management practices. Safety atmosphere, a concept that outlines how workers perceive common safety rules, procedures, practices and behaviours that are rewarded in workplaces or work groups, yet we didn't look into it [28]. Despite its reputation as a leading indicator of safety outcomes across sectors and nations, no agreement exists on what defines a "safety environment" [14]. Perceptions of management values, safety communication, safety practices, safety training, and safety systems are important to Neal et al. [16], while other researchers have looked at many other aspects of the safety environment. According to Seo [29], safety climates may be operationalised as shared impressions of management commitment, supervisor support, coworker support, employee involvement, and competency level.

Moreover, safety atmosphere encompasses CEO commitment, emergency response, and employee perception of risk [30]. Cavazza and Serpe [31] examined the safety concerns of companies and top managers, as well as the pressures of the workplace and the attitudes of supervisors toward safety. However, past empirical research has either taken safety climate as a single measurable variable or as a latent variable when operationalising the safety climate construct, which implies that safety climate in diverse studies represents distinct perspectives of the safety environment. As a result, we contend that views of safety management procedures have considerable implications for staff morale and productivity.

A key part of textile safety is management commitment to safety, which is addressed in this article, along with training and incentives for staff engagement in safety. Primarily, due to violations of safety production rules and regulations at the organisational and management level, textile accidents are frequently caused by human error, including excessive capacity and overtime production, giving instructions that go against rules and regulations or pressuring workers to take on dangerous tasks.

Accidents such as these may be traced back to management's failure to implement fire protection procedures. Workers were forced to work underground following the first three explosions due to pressure from supervisors/managers, in violation of safety regulations and rules. This shows a low level of management commitment to safety, according to a State Administration of Work Safety investigation conducted in 2013. The management in Pakistan's textile sector didn't think it was worthwhile to involve workers in safety-related decisions because many of them lacked relevant knowledge or an understanding of the big picture of safety management, even though this could be corrected through safety training. Further studies [32] have shown that China may be characterised as a country with a large power distance, where authorities are revered and people are less inclined to challenge management choices. Coal miners are unlikely to raise concerns about management choices if they see them from this viewpoint. Workers must be trained to improve their safety awareness and knowledge, and to improve their ability to use this knowledge in making judgments rather than blindly following the instructions of superiors, who often violate safety rules and regulations. Littrell [33] argued that this training is required to bring about change; another way of putting it is that management must promote proactive employee engagement in safety-related concerns and training to strengthen the ability of workers in their day-to-day job to make autonomous choices [33].

Because many employees in this industry are strapped for cash, they tend to overwork themselves and adopt shortcuts to increase output. These factors led to a concentration on the role played by management commitment to safety, training in safe work practices and systems of compensation in the textile industry rather than other management techniques.

Safety knowledge and motivation have a direct influence on safety performance; thus, these four management practices should have a distal impact on safety performance since they are distal in their interactions with safety performance.

Payment structure stands out because we suggest it as a modulator for links between safety knowledge/motivation and behaviour rather than as a distal precursor to conduct. Our emphasis was just on time-rate compensation vs. piece-rate pay, and not on a comprehensive reward system that may include safety bonuses or incentives to encourage workers to learn about safety and practice safe behaviour.

HRM Practices proximal factors, and employees' safety performance

As pointed out, four management strategies, management attention to safety, security preparation, employee interest in safety, and pay methods, are the key focus of this document, and we recommend the inclusion of these practices to have beneficial effects on the safety of the organisation. More proximal determinants (e.g., safety information and motivation for security), which serve as mediators, often indicate their impact on security efficiency. We also assume a lower interaction between management processes and safety results where people lack the necessary expertise and safety skills or are not motivated to work hard to implement security behaviour. The following segment discusses the mediation impact on the interaction between management activities and safety results of security expertise and motivation.

Safety knowledge and safety motivation

In line with our conceptual model in figure 1, we wanted to see a clear positive connection between protection and success because of good behaviour. Awareness of safety is a precondition. Security motivation relates to "one's desire to work for safety behaviours, and their valence" [21] and safety motivation was expected to be directly linked to safety success, since it is motivation that determines performance. Safety knowledge and safety motivation are critical factors in enhancing workplace safety performance. Safety knowledge equips employees with the necessary understanding of hazards, risk management strategies, and proper safety procedures, enabling them to recognise potential dangers and respond effectively to emergencies. However, knowledge alone is insufficient without the motivation to apply it consistently. Safety motivation drives employees to adhere to safety protocols, take personal responsibility for their actions, and actively contribute to a culture of safety within the organisation. When employees possess both knowledge and motivation, they are more likely to engage in proactive safety behaviours, report hazards, and comply with safety regulations, ultimately reducing the likelihood of workplace accidents and injuries. Organisations can foster these attributes through comprehensive training programs, incentive-based safety initiatives, and strong leadership commitment to safety. By integrating both knowledge and motivation into workplace safety strategies, organisations can achieve higher safety performance and create a more secure working environment.

Management practices and employee safety behaviours

We propose that the philosophy of social exchange may help to understand the relationship between management, protection incentives and safety. Based on the principle of social exchange theory, transition and equilibrium may be considered as a mechanism of agreed exchanges and dealings between the parties, resulting in a convention on fair trade and reciprocal exchange [34, 35]. In particular, workers may establish an inherent obligation to reciprocate in a manner that benefits them as they consider the welfare and well-being of their organisation [36]. Examples involve compliance with the safety protocols defined, execution of high-standard core tasks and participation in security citizenry [37]. Individual employees should be encouraged to cooperate and participate in safety operations if their employers and organisations are committed to protection, inspire employees to take safety-related decisions and take security training seriously. The following parts explain in greater depth how management activities can influence safety efficiency.

Security management dedication is an important part of the performance of the security programs of a company [38]. The argument has been made that such commitment should be expressed in ways that are compliant with staff [39]. Safety issues have been highly prioritised in company meetings and production planning [40], as well as through the participation of top management in security activities on a routine basis [41]. According to Vredenburgh [26], staff would probably be inspired to learn more about safety and practice if they comply with a high degree of management dedication to safety, which will help improve safety efficiency.

A good safety management strategy includes such a technique, according to the research. As a result, workers feel empowered to make good contributions to workplace safety and the company as a whole, which motivates them to keep learning and applying what they've learned about safety in the past to determine whether their efforts are having the desired effect on both. To enhance safety results, well-designed and effectively delivered safety training has long been recognised as a crucial HR practice. As a result, workers become more knowledgeable about occupational safety and health (OSH), their skills and capacities to spot risks and potentially hazardous situations improve, and they are given the tools to make incidents more predictable [24–26]. The companies with lower accident rates have good safety training for their employees, according to several studies [16, 42]. This is important for safety performance because through training, employees can potentially operationalise knowledge and the capability of applying acquired knowledge to solve practical issues [43].

Institutional pressure

Institutional theory holds that organisations have a propensity to adhere to socially acceptable standards and practices to be structurally compatible with their particular institutional setting [44]. Institutional pressures may come from explicit laws (regulations and mandates) as well as informal limitations (norms, practices, and beliefs), and how organisations react to these forces will define their legitimacy as an institution [45]. By DiMaggio and Powell [44], organisational behaviour is shaped by three forms of pressures: coercive, mimetic, and normative forces.

Safety performance

Even though several researchers have examined general employee behaviours in various 'critical skills occupations' or industries [16, 46–49]. A company's overall safety performance was characterised by Burke and Dunlap [43] as behaviours across all jobs that contribute to the safety and well-being of all stakeholders, not just the company itself. When looking at the performance ratings of 550 hazardous waste workers, researchers found that using personal protective equipment, engaging in risk reduction practices, communicating health and safety information, and exercising rights and responsibilities were all important safety performance factors (refer to Method section for definitions). They proposed that safety information, which is typically learned via classroom instruction, has an important role in how well workers perform on these dimensions.

One possible outcome of training is proceduralization of knowledge, which refers to the capacity to use previously acquired information in addressing real-world situations [50]. The more related or comparable content people see in various presentations during refresher training, the easier it will be for them to apply what they've learned from the new materials [51]. As an example, Stout et al. [52] discovered that aviation training improved knowledge structures, or how ideas are organised, and how they are connected within a domain (e.g., safety). There is a strong argument to be made that Anderson's notion of proceduralization of knowledge includes the concept of knowledge structures. So, for practical issue solving, well-organised storage of ideas is likely required, since retrieval of information is a prerequisite to the application of previously-stored knowledge.

Once a person can use knowledge, it must be translated to the workplace to have an impact on how well they perform. Transfer of training is described by Baldwin and Ford [53] as the generalisation and preservation of learnt content in the work setting across time. Only when people have the chance to demonstrate the information and skills they've gained will mastery and preservation of knowledge and skills improve the transfer to work [54].

More than one study has provided empirical evidence for predicted positive connections between the quantity of safety training and perceived safety

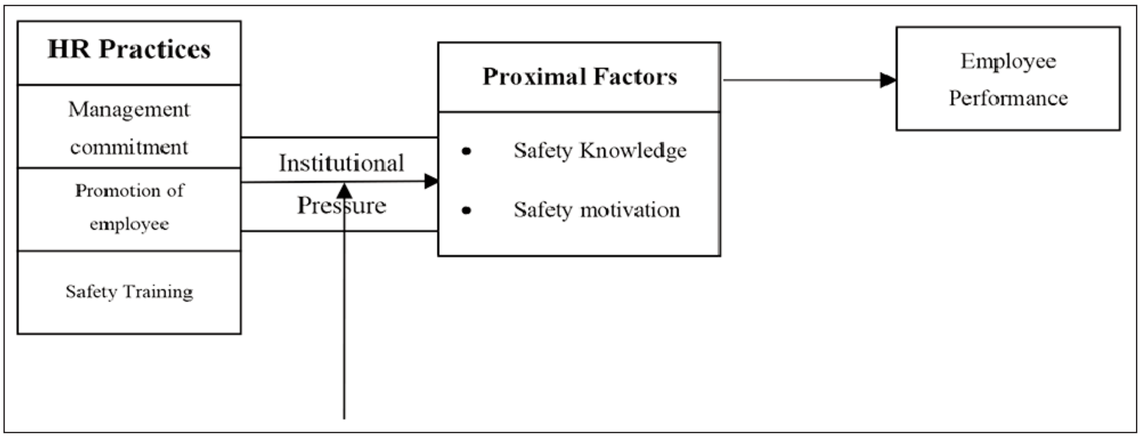

Fig. 1. Theoretical framework

knowledge, as well as assessments of safety performance by employees and supervisors [16, 43]. As an illustration, Burke and Dunlap [43] found a positive correlation between worker safety knowledge and worker performance on specific dimensions of safety performance (i.e. using personal protective equipment), such as risk reduction practices and communicating health and safety information (i.e. communicating health and safety information.

Burke and Dunlap [43] analyse combined data from two organisations (U.S. Department of Energy contractors) in the nuclear waste industry located at the same site. Their analyses investigating safety knowledge-safety performance relationships focused heavily on the construct validity of their confirmed safety performance dimensions. To the extent that the two organisations varied concerning organisational climate, the above literature would lead to the general expectation that the magnitudes of the safety knowledge-safety performance relationships observed by Burke and Dunlap [43] might vary across the organisations. According to anecdotal reports from site experts, the two organisations studied by Burke and Dunlap [43] did differ in organisational climate for the transfer of safety training. One organisation, hereafter referred to as Organisation A, was thought of by site experts as having a more strategically focused (and less restrictive) organisational climate for the transfer of safety training than the second organisation, hereafter referred to as Organisation B. In the current study, the climates of these two organisations were empirically examined according to the conceptualisation of organisational climate for the transfer of safety training detailed below.

METHODOLOGY

The survey of this study was distributed online and offline distribution and by using a random sampling method [55]. An offline distribution was selected because of the validity of the questionnaire. We sent them a questionnaire by the HR managers, lower-level managers and visited their companies.

Furthermore, online distribution was viewed as a faster method for data collection than offline distribution. The online distribution may be making it possible for the survey to take longer because respondents can fill it in at their discretion.

An online version has been created using Google Forms, and the query is complete. Most feedback is available to ensure that the data collection process is selected at a given time. A high response rate is recommended by sending a questionnaire to the participants via email and LinkedIn. A total of 165 questionnaires were used for data analysis. The instruments which were used in the present study and the demographics of the respondents are shown in the tables 1 and 2.

Table 1

STUDY'S INSTRUMENTS			
Description	**Items**	**References**	**α**
Management commitment	7	[16, 56]	0.70
Encouragement of employee involvement in safety	2	[16, 56]	0.86
Safety training	4	[16,56]	0.82
Safety knowledge	4	[16]	0,87
Safety motivation	4	[16]	0.91
Safety compliance	4	[16]	0.89
Safety participation	4	[16]	0.78
Safety performance	4	[16]	0.82
Institutional Pressure	8	[57–60]	0.86

DATA ANALYSIS

Measurement model

The measurement model analysis explains how dimensions of latent variables are dignified regarding their measurement properties and perceived (observed) items. This specific section highlights the evaluation of the outer model (measurement) by assessing the internal consistency, items' reliability, discriminant validity and convergent reliability [61, 62].

Table 2

DEMOGRAPHICS OF THE STUDY		
Items	**Frequency**	**Percentage (%)**
Gender		
Male	128	78
Female	37	22
Age		
Below 30 Years	95	58.0
31–35	25	15.5
36–40	24	11.0
41–45	11.55	7.0
Above 46 Years	14.02	8.5
Marital status		
Single	72	43.5
Married	93	56.5
Education level		
Intermediate	8	5.0
Bachelors	60	36.5
Masters	64	38.5
MS/M. Phil	28	17.0
PHD	5	3.0
Job title		
Supervisor	52	26.0
Senior Supervisor	57	28.5
Manager	77	38.5
Officer	12	6.0
Other	2	1.0
Working experience		
Below 2 years	54	27.0
3–5 years	46	23.0
6–8 years	42	21.0
above 9 years	58	29.0

Table 3

MEASUREMENT STATISTICS OF CONSTRUCTS				
Constructs, Dimensions, Items	**Item loading**	**AVE**	**CR**	**α**
Management commitment (MC)				
MC1	0.803	0.904	0.924	0.636
MC2	0.740			
MC3	0.785			
MC4	0.744			
MC5	0.813			
MC6	0.856			
MC7	0.835			
Institutional pressure				
IP1	0.731	0.816	0.854	0.595
IP2	0.764			
IP3	0.724			
IP4	0.613			
IP5	0.666			
IP6	0.711			
Safety knowledge				
SK1	0.827	0.831	0.887	0.663
SK2	0.780			
SK3	0.826			
SK4	0.823			
Safety motivation				
SM1	0.820	0.882	0.919	0.740
SM2	0.876			
SM3	0.821			
SM4	0.888			
Employee safety performance				
ESP1	0.917	-	-	-
ESP2	0.871			
ESP3	0.785			
ESP4	0.849			
Safety training				
ST1	0.849	0.841	0.894	0.678
ST2	0.827			
ST3	0.747			
ST4	0.866			
Employees promotion				
EP1	0.895	0.752	0.850	0.739
EP2	0.823			

In total, 45 items were used to explain the four constructs of the model. By using the PLS algorithm for all reflective constructs were accomplished. The reflective scale's reliability was assessed by the SMART PLS algorithm through the estimation of convergent reliability and discriminant validity. The following model depicts latent variables (circles) and their measuring items (rectangles), as shown in figure 2.
These "Results show that all latent variables in the model are reflective by nature and it is defined by results that all-inclusive quality of the reflective variable's measure of PLS loadings, Cronbach's alpha, constructs 'AVE & composite reliability", which is shown in table 5.

First-order constructs

By evaluating the first-order construct, the item's loading was assessed. Regarding Management Commitment, it consisted of seven items. The outer loadings fluctuated from 0.740 to 0.856 for the concerned items, and all items are significant at the level of 0.5, as shown by the *t*-value results. Institutional Pressure with no dimension, but it comprises six items. The outer loadings fluctuated from 0.613 to 0.764 for the concerned items, and all items are significant as shown by the *t*-value results. Safety knowledge was assessed by four items with no dimension. The outer loadings fluctuated from 0.780 to 0.827 for the concerned items, and all items are significant at the level of 0.5, as shown by the *t*-value

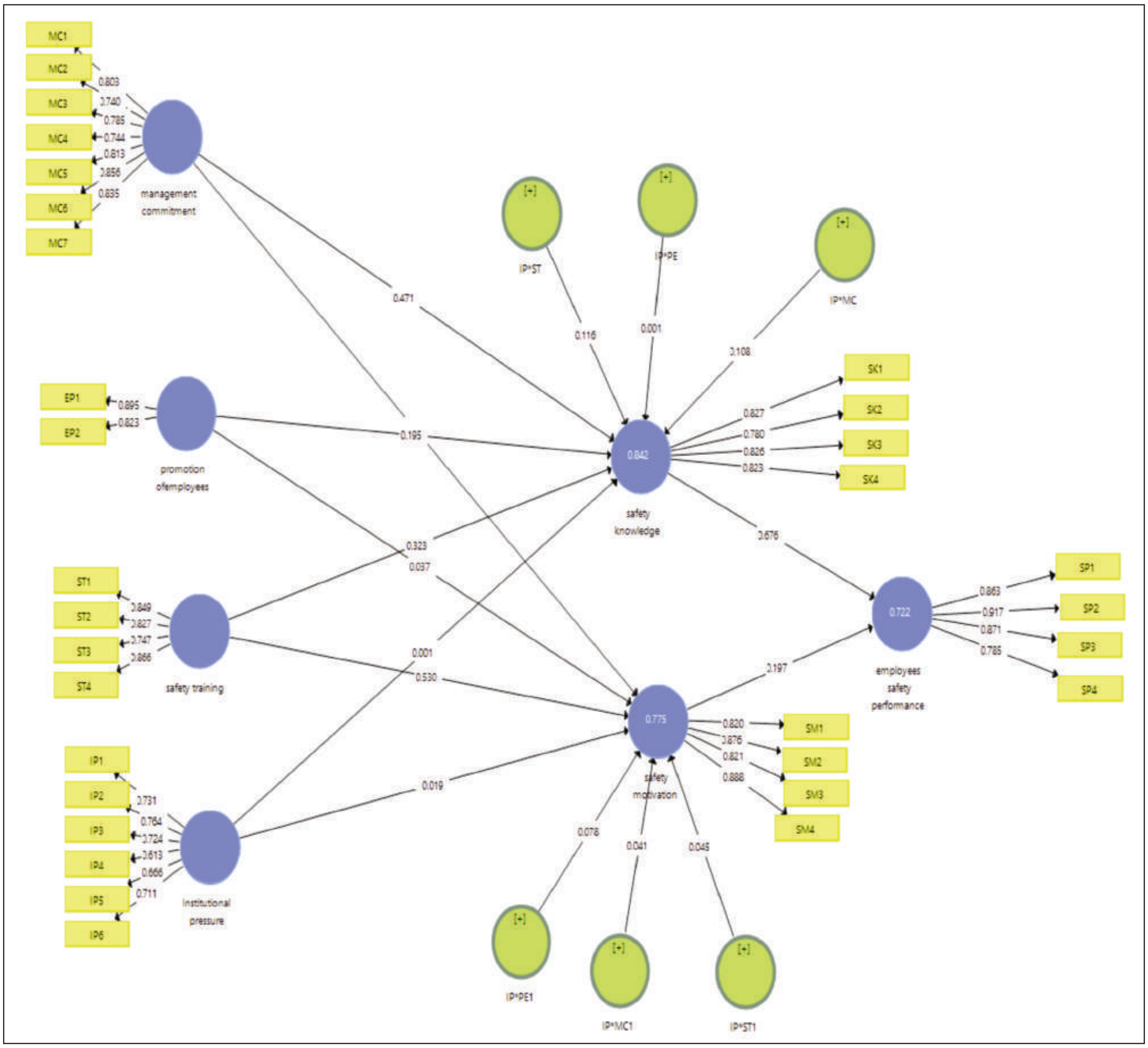

Fig. 2. Measurement model

results. Safety Motivation was assessed by four items, and it has no dimension as well. The outer loadings fluctuated from 0.85 to 0.91 for the concerned items, and all items are significant at the level of 0.5, as shown by the *t*-value results.

Item reliability

Internal consistency reliability is the first category to be assessed. Cronbach's alpha (α) is a traditional criterion for internal consistency, which gives an estimate of the reliability based on the intercorrelations of the observed indicator variables. It has been shown in table 3, all items' reliability is robust, as it can be seen in table 5, Cronbach's alpha (α) is greater than 0.7. Moreover, composite reliability (CR) fluctuate from 0.94 to 0.98, which surpasses the prescribed limit of 0.70, affirming that all loadings used for this research have shown up to a satisfactory indicator of reliability. Ultimately, all items' loadings are over the 0.6 cutoff [63, 64].

Convergent validity

Convergent validity refers to the extent to which measures of the same construct (variable) correlate positively with other measures. By using the Domain Sampling Model, the items of a specific construct are considered as alternative dimensions to measure the same construct. Hence, the indicators of a reflective construct should share a huge amount of variance. Analysts take into account the outer-loadings of the items and the average variance extracted to examine the convergent validity of a specific variable. By utilising composite reliability and average variance extracted scores, convergent validity was estimated [65]. It is elaborated in table 3 average variance extracted of all the indicators is greater than 0.50, and composite reliability is higher than 0.70, which is an acceptable threshold of convergent validity and internal consistency. It is stated that a value of composite reliability, i.e. not less than 0.70, is acceptable and evaluated as a good indicator of internal consistency [66]. Moreover, Average variance extracted scores more than 0.50 demonstrate an acceptable convergent validity, as this implies a specific construct with greater than 50% variations is clarified by the required indicators.

Discriminant validity

In empirical standards, discriminant validity can be described as the degree to which a variable is specifically different from another variable. Therefore, when the discriminant validity is established, it is understood that a variable is distinctive and possesses uniqueness that is not entitled to another Variable in the model. Particularly, scholars have depended on two proportions of discriminant validity. The cross-loadings are normally the main way to deal with the discriminant validity of variables. Outer loadings of an indicator with related variables must be considerably greater. Compared to its cross-loadings, which specify its correlation with other constructs. The ideal approach to evaluate and report cross-loadings is in a table column for the variable and rows for the indicators. Likewise, HTMT can be explained it is a ratio of linking trait relationship. HTMT is the mean of all correlations of items (indicators) over a construct, estimating various constructs concerning the mean of the average relationships of indicators estimating a similar construct. In fact, the HTMT approach is an evaluation of what the genuine connection between two constructs would be, if they have been measured perfectly. This genuine relationship is additionally referred to as a disattenuated relationship. A disattenuated relationship between two constructs near 1 shows an absence of discriminant validity.

Another to assess the measurement model, the HTMT ratio of relationships was utilised to evaluate discriminant validity, in light of the multitrait-multimethod matrix. The HTMT element that was more than 0.85 demonstrates an issue of discriminant validity [67]. In this study, all elements are according to the criteria. The specific research, in this manner, demonstrates that the estimation model has built up its discriminant validity.

In conclusion, the estimating model has passed the reliability and validity tests. The validity and reliability tests show that the estimated model used in this study is valid and suitable for use in evaluating the structural model's parameters.

Structural model

The Structural equation model (SEM) was assessed dependent on five criteria: (1) path coefficient (β) that shows the either relationship is weak or strong between constructs (2) level of variance clarified or R square (R^2) which generally was called regression score, (3) standardized root mean square residual (SRMR) (4) *t*-values significance which clarify the relationship among variables are significant or not. (5) The Q2 that estimates how well the model reproduces the perceived values and its estimates of parameters [68].

Path Coefficient (β) and *t*-value

In this study, the path coefficient was used to assess the relationship of the variables as hypothesised. The resampling criteria of bootstrapping were run by inducing statistical inference and observing the influence of confidence intervals of path coefficients [69]. Table 7 indicates the results of 165 sample bootstrap analyses, including (1) standardised path coefficient (β), (2) corresponding *t* and *p* values.

This study used SEM Analysis, tests like PLS-algorithm, PLS-blindfolding and PLS-bootstrapping to test all the Hypotheses. The latent variables are entered into the model and connected in a path, HR practices as an independent variable, safety motivation and safety knowledge as mediators, institutional pressure as a moderator and employee's safety performance.

Table 4

DISCRIMINANT VALIDITY

Variables	Institutional pressure	Management commitment	Promotion of employees	Safety knowledge	Safety motivation	Safety promotion	Safety training
Institutional pressure	0.703						
Management commitment	0.332	0.898					
Promotion of employees	0.333	0.742	0.86				
Safety knowledge	0.301	0.871	0.787	0.854			
Safety motivation	0.265	0.821	0.716	0.825	0.852		
Safety promotion	0.324	0.723	0.829	0.844	0.774	0.86	
Safety training	0.27	0.823	0.763	0.812	0.722	0.79	0.823

Note: The square root of AVE' is visible on the main diagonal. Correlations are lower left of the diagonal.

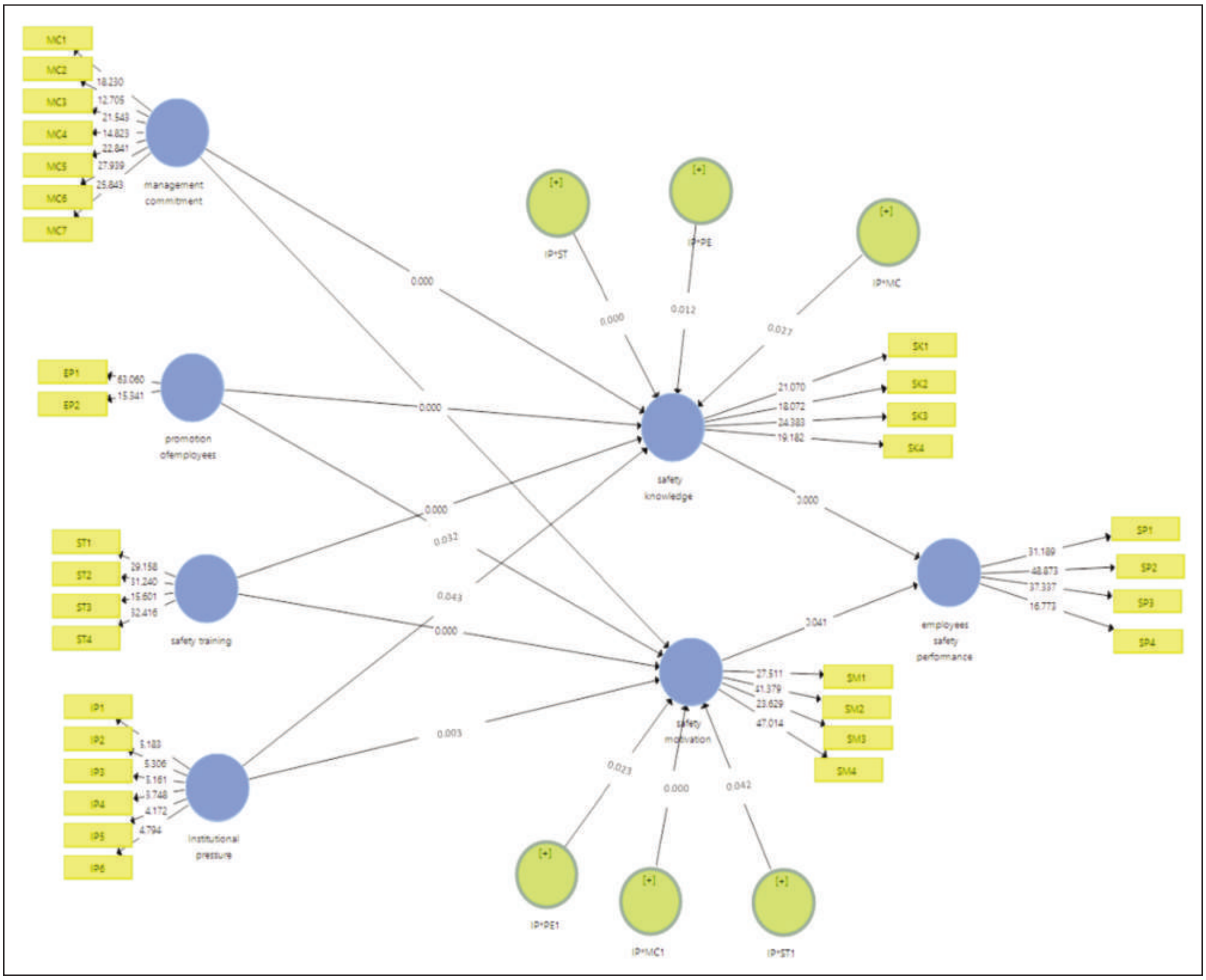

Fig. 3. Bootstrapping

Table 5

RESULT OF STRUCTURAL MODEL AND HYPOTHESES TESTING				
Hypothesis	**β**	**|*t*-value|^**	***p*-value**	**Decision**
Management commitment 8 → Safety knowledge	0.471	6.276	0.000	Supported
Management commitment → Safety motivation	0.371	5.754	0.000	Supported
Promotion of employees → Safety knowledge	0.195	3.545	0.000	Supported
Promotion of employees → Safety motivation	0.037	6.729	0.032	Supported
Safety motivation → Employees' safety performance	0.197	2.045	0.041	Supported
Safety training → Safety knowledge	0.323	3.750	0.000	Supported
Safety training → Safety motivation	0.530	9.496	0.000	Supported
Safety knowledge → Employees' safety performance	0.676	7.777	0.000	Supported

The first hypothesis shows that management commitment has a significant impact on safety Motivation. The results show there is a significant impact on safety Motivation by managing management commitment ($\beta = 0.471$; $t = 6.276$, $p < 0.05$), supporting H1. The second hypothesis shows that management commitment has a significant impact on safety motivation. The results show there is a significant impact on safety motivation by managing management commitment ($\beta = 0.371$; $t = 5.754$, $p < 0.05$), supporting H2.
It is a hypothesis that shows the promotion of employees has a significant impact on safety knowledge. The results show there is a significant impact on safety knowledge by management commitment ($\beta = 0.195$; $t = 3.545$, $p < 0.05$), supporting H3. The Promotion of employees has a significant impact on safety motivation. The results show there is a signifi-

Table 6

HYPOTHESIS TESTING RESULT MODERATING EFFECTS				
Hypothesis	**β**	**|*t*-value|^**	***p*-value**	**Decision**
IPp*MC1 → Safety motivation	0.041	0.406	0.000	Supported
IP*MC_ → Safety knowledge	0.108	0.825	0.027	Supported
IP*PE → Safety knowledge	0.001	0.009	0.012	Supported
IP*PE1 → Safety motivation	0.078	1.118	0.023	Supported
IP*ST1_ → Safety motivation	0.045	0.389	0.042	Supported
IP*ST_ → Safety knowledge	0.116	0.967	0.000	Supported

cant impact on safety motivation by managing management commitment ($\beta = 0.037$; $t = 6.729$, $p < 0.05$), supporting H4.

It is a hypothesis that shows safety motivation has a significant impact on employees' safety performance. The results show there is a significant impact on safety motivation by managing employees' safety performance ($\beta = 0.197$; $t = 2.045$, $p < 0.05$), supporting H5. The safety training has a significant impact on safety knowledge. The results show there is a significant impact on safety training by safety knowledge ($\beta = 0.323$; $t = 3.750$, $p < 0.05$), supporting H6.

It is a hypothesis that shows safety training has a significant impact on employees' motivation. The results show there is a significant impact on safety training by managing employees' motivation ($\beta = 0.530$; $t = 9.496$, $p < 0.05$), supporting H7. The safety knowledge has a significant impact on safety employee's safety performance. The results show there is a significant impact on safety knowledge by employees' safety performance ($\beta = 0.676$; $t = 7.777$, $p < 0.05$), supporting H8.

Testing the moderating effect

A moderating impact happens when a third factor (so-called mediator) decreases or improves the quality or direction of the relation between an independent and dependent variable. A moderator variable communicates under what conditions an independent variable impacts on dependent variable. Considering a causal variable, a moderator is at a similar level as an independent variable. A few measurable procedures have been predicted in testing moderating impacts, contingent upon whether the moderator is categorical or continuous.

At the point when the exogenous variable affects on endogenous variable, it depends upon the estimations of another variable, which moderates the link. Vinzi, Chin, Henseler and Wang, In their study in two thousand ten evaluated different approaches for testing moderation in Smart PLS-SEM as far as their relevance to statistical power & reflective and formative measures. Institutional pressure moderates the relationship between HR practices and proximal factors. The association between management commitment, safety training, employee promotion, safety motivation, and safety knowledge are shown in the table. All the moderating effects are positive and significant. It shows significant results which are consistent with the previous research; the results show that institutional pressure influences the relationship between HR practices and Proximal factors significantly and positively.

DISCUSSION

The primary goal of this research was to determine the relationship between some essential management practices and safety performance, namely safety compliance and engagement. Management commitment to safety, safety training, promotion of employee engagement in safety, and payment mechanisms are all examples of these management approaches. The first three practices are posited as distal antecedents of safety performance that impact safety knowledge and motivation, whereas the final one is expected to modulate the link between safety knowledge/motivation and safety performance. In addition, the function of safety knowledge and safety motivation as mediators in safety management was investigated.

The findings revealed that all three management methods had an impact on safety motivation and were all positively connected with safety knowledge. Only safety training and encouraging employee engagement in safety were shown to affect safety knowledge, whereas workers' opinions of management commitment to safety had no effect.

Management commitment, it might be claimed, provided workers with an overall image of management's interest in occupational health and safety, which was represented in a variety of activities and initiatives aimed at safety [14]. This overall perception of employers' safety concerns had little effect on individual safety knowledge, but it did drive workers to engage in safe activities.

We discovered that management commitment and employee engagement in safety may have independent, direct impacts on safety compliance and participation in our study of the connection between management practices and safety performance. Safety training influenced both direct and indirect safety compliance, as well as safety involvement, through safety knowledge and motivation. Notably, the direct impact of safety training on safety compliance was only significant among workers who were paid on a time-rate basis, implying that the effect of safety training on safety compliance for employees paid on a piece-rate basis was entirely via the mediators. Such findings show that training alone is inadequate to assure safety, and firms must motivate workers and ensure that they apply what they've learned in the training program to real-world challenges. This is particularly critical for workers who are working under tight deadlines.

Employee engagement in safety measures, according to [70], fosters learning, allows workers to become more proactive, improves problem-solving abilities, and permits preventative action. The present research confirmed their results, indicating that increasing employee engagement in safety had a direct impact on safety performance as well as an indirect impact due to increased safety knowledge and motivation. As a result of this study, managers at all levels need to delegate authority and influence to lower-level workers so that individuals feel empowered [71]. More employee influence over the organization's safety practices may motivate employees to take more responsibility in their work while also encouraging others to do so (high safety participation) in the context of safety management, increasing their likelihood of adopting the value of working safely (high safety compliance) and working toward the organization's goals [72]. If people have more power and responsibility, this may lead to an increase in the number of people who take safety seriously and apply their expertise in the workplace.

Individual safety habits were impacted by managerial commitment. Management commitment to safety had a stronger influence on workers' earning piece rates than on those earning time rates, and the beneficial impact of management commitment to safety on safety motivation was limited to those earning piece rates, as shown in the table. Employees often turn to their supervisors for cues to influence their safety behaviours, according to [73], when there is a contradiction between the pressure to produce and the emphasis given to safety. When managers are extremely devoted to safety, the probability and willingness of workers experiencing production challenges due to piece-rate pay to participate in and perform safety behaviours improves, since they have a direct influence on the allotted incentives for employees [74].

The following conclusions may be derived for practitioners and organisations. Managers must first show their commitment to safety by communication and actions, such as frequent meetings, investment in workplace safety initiatives, and incentive programs [75]. Second, businesses must establish systematic, comprehensive health and safety training programs for new hires, as well as ongoing safety re-education and retraining for their personnel. Furthermore, for safety training to be more successful, it should be followed by goal-setting programs and performance reviews [26]. Organisations are also urged to include employees in detecting safety issues, consulting with them on safety issues, and empowering them to make safety-related choices, especially as worker engagement is a critical component in safety management [14, 56]. Employees who are engaged in the formulation of safe-work measures, for example, are more likely to identify with and follow such procedures [76]. Furthermore, if they are given opportunities to contribute to workplace safety by identifying risk behaviours, monitoring the workplace environment, and sharing their experience with safe production in training programs, they are more likely to be aware of risky behaviours and motivated to follow workplace safety rules and procedures.

CONCLUSION

The research discovered that poor occupational health and safety procedures for textile workers affect worker performance and output. Respondents were unanimous in their belief that risks such as noise, fire, smoking, fatigue, drinking alcohol, job stress, cotton and dust particles exist to some extent, and that these hazards have a direct or indirect impact on employees' health. Occupational Health and Safety Practices (OHSP) include; awareness of clinic, awareness of hazards, better health makes good production, workers satisfaction with top management's attitude, awareness of preventive measures, influence of mobile on production, inaccurate instrument cause trouble, and periodic medical tests since working was being done in their organizations, while; dust mask, ear plug, pre-employment medical examination, training on hazard prevention. In addition, respondents were dissatisfied with the use of personal protective equipment at work.

LIMITATION AND FUTURE DIRECTION

There are various limitations in the existing research. First, all data were gathered from textile organisations of Faisalabad and Lahore, which may have minimised the variety in replies, implying that generalisations should be used with care. In addition, due to a lack of adequate numbers of participating organisations, the unit of analysis was confined to the person level rather than the organisational level. Future research might address this restriction by broadening the scope of the study to cover more of Pakistan's textile industry.

Second, this research primarily employed self-report data from individuals, including measures of perceived organisational management practices, safety knowledge and motivation, and safety performance obtained from the same people. It was challenging to demonstrate causal linkages since the research was cross-sectional. The causal association between these factors may be established in a future study using longitudinal methods. Qualitative data might also aid in the development of a fuller, more thorough understanding of the processes by which management practices influence safety performance. The connections between the variables tested may have been harmed by common method variance (CMV) due to the cross-sectional character of the study methodology [77]. For example, the survey introduction said that respondents' anonymity and confidentiality would be protected, and that they should answer the questions on distal antecedents and proximal determinants first, before moving on to the part on safety performance. Furthermore, the questionnaire separated conceptually related assessment items to limit the impact of contextual hints and respondents' propensity to utilise past responses to fill in memory gaps [78].

In conclusion, this work adds to the small body of knowledge on the relationship between management and safety performance in Pakistan's textile industry. Safety is influenced directly by management commitment to safety, safety training, and staff participation [79], as well as indirectly via the mediating effects of safety knowledge and motivation, according to the research. This exemplifies the critical role that these practices have in improving workplace safety [80]. Surprisingly, piece-rate compensation had no detrimental impact on individual safety performance habits, according to this research. Because there is so little empirical research on the impact of piece-rate pay on health and safety in the textile industry, we were unable to compare our results to others in the literature. More study on this subject is critically needed in the future. These results contribute to the expanding body of knowledge about how management practices affect employee safety. We expect that the research will help practitioners understand how to enhance workplace safety via several processes.

ETHICS STATEMENT

All methods were performed by the Declaration of Helsinki and approved by the Research Ethics Committee of Faisalabad Business School, National Textile University Faisalabad, Pakistan (# FBS-NTU-27-145-8).

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The influence of the colour and the surface area occupied in the camouflage pattern on the reflection index

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ABSTRACT – REZUMAT

The influence of the colour and the surface area occupied in the camouflage pattern on the reflection index

Textile camouflage structures designed for weather protection, combat suits, and military uniforms for land forces are defined by their physical, mechanical, and optical properties. An analysis of the statistical populations of reflection within the wavelength range of 860–1200 nm revealed the degree of dispersion in the measured values. A novel method was developed to determine the weight of monochromatic areas on a multi-coloured surface. Various camouflage textile structures were examined to investigate the correlation between reflection indices and the weight of the single-coloured regions. Several parameters were identified, including the colour index, the range of colour reflectance, the area covered by each colour, and the weight of the colour-covered region. To assess the degree of reflection for each colour within the spectral range of 860–1200 nm, the median of the reflection values was calculated, as it provides a more representative measure of the overall reflective properties. The frequency distribution of these values was analysed, leading to the establishment of a ranking of camouflage types based on their reflection coefficients, starting with the lowest reflection value. Regression curves were derived for the reflection index values at wavelengths between 860–1200 nm, with increments of 10 nm. These initial regression curves, along with those weighted by colour area, include regression equations for the analysed textile structure variants. These equations enable the calculation of the regression index as a function of wavelength.

Keywords: *camouflage textile structures, reflection, wavelength range, optical properties, regression curves*

Influența culorii și a suprafeței ocupate în modelul de camuflaj asupra indicelui de reflexie

Structurile textile de camuflaj destinate protecției împotriva intemperiilor, echipamentelor de luptă și uniformelor militare pentru forțele terestre sunt caracterizate prin proprietăți fizice, mecanice și optice specifice. În cadrul acestui studiu, analiza populațiilor statistice de reflexie în intervalul de lungimi de undă 860–1200 nm a evidențiat gradul de dispersie al valorilor măsurate. A fost propusă o metodă inovatoare pentru determinarea ponderii zonelor monocromatice pe o suprafață policromă. Au fost investigate diverse structuri textile de camuflaj pentru a stabili corelații între indicii de reflexie și ponderea zonelor colorate uniform. Parametrii analizați au inclus indicele de culoare, intervalul de reflectanță al fiecărei culori, suprafața acoperită de fiecare culoare și ponderea corespunzătoare a fiecărei regiuni colorate.
Pentru a evalua nivelul de reflexie al fiecărei culori în intervalul spectral menționat, a fost utilizată mediana valorilor de reflexie, considerată un indicator mai reprezentativ al comportamentului optic general. Distribuția frecvenței valorilor de reflexie a permis realizarea unei clasificări a tipurilor de camuflaj în funcție de coeficientul de reflexie, începând cu valorile cele mai scăzute. Curbele de regresie au fost construite pentru indicii de reflexie corespunzători lungimilor de undă cuprinse între 860 și 1200 nm, la un pas de 10 nm. Atât curbele de regresie inițiale, cât și cele ponderate în funcție de suprafața acoperită de fiecare culoare, includ ecuații de regresie pentru variantele analizate ale structurilor textile. Aceste ecuații permit calculul indicelui de regresie în funcție de lungimea de undă, oferind o bază solidă pentru proiectarea avansată a materialelor de camuflaj.

Cuvinte-cheie: *structuri textile de camuflaj, reflexie, interval de lungimi de undă, proprietăți optice, curbe de regresie*

INTRODUCTION

Protective textiles used in military applications must fulfil a variety of functional requirements, including durability, resistance to environmental conditions and ballistic threats, while also being comfortable and lightweight. The Research and Markets report on the Smart Textiles for Military Equipment Market, by Type, Application, End-User, and Region (2024–2032), highlights that the global smart textiles market for military applications reached USD 890.4 million in 2023 and is projected to reach USD 2,535.5 million by 2032, registering a growth rate of 12.33% during this period. By 2027, the global military smart textiles market is expected to be dominated by the camouflage sector [1].

Camouflage has always played a major role in military operations. Its purpose is to blend combat suits and equipment with the natural environment, reducing the visibility of soldiers and their tools. Today, camouflage involves more than just design and colour; it requires several key elements. For example, camouflage effective in daylight may be rendered useless when viewed through night-vision technology. In such cases, an infrared (IR) signature becomes essential. Defining an exact IR reflectance corridor for each colour in a pattern is crucial for good daytime camouflage that remains effective in twilight or complete darkness at night [2]. In addition, these textiles must perform well under various environmental conditions and across a range of wavelengths on the electromagnetic spectrum. As infrared sensing technology advances, the focus of protective textile research has shifted from visible camouflage to camouflage in the IR region. Smart textiles, capable of monitoring and reacting to the wearers or environmental stimuli, have been incorporated into protective fabrics to enhance camouflage in the IR spectral range [2–4].

Conducting military operations requires a degree of stealth to operate covertly and therefore avoid detection. Traditionally, being able to blend into the surrounding environment under daylight was the key, when visual camouflage was king; however, as times have progressed, so has technology; enter the Infrared camera and night vision goggles. With the rapid development of surveillance and acquisition devices, it became imperative to develop camouflage textiles that could protect objects from detection by various sensors in a wide spectral range. As sensor systems continue to be refined, the performance of camouflage materials must be continually updated [5], reducing thermal emissions for various applications. Objects emit infrared radiation detectable by devices, making military targets easily identifiable. Infrared camouflage mitigates detection by lowering an object's infrared radiation, achieved by methods such as reducing surface temperature, which is crucial in designing military tents with IR camouflage, considering water repellence and antibacterial features [6]. IR protection involves using materials or coatings that either absorb or reflect infrared radiation, thereby reducing the heat signature of soldiers.

The latest breakthroughs in military equipment will be implemented soon, and by 2025 the military will have a smart uniform, able to instantly adapt its colour in perfect correlation with the geographical area and fauna, but also to change the insulation properties to ensure an optimal temperature depending on the environmental conditions specific to the areas in theatres of operations where the military is operating. To camouflage military equipment and personnel, synthetic green pigments are incorporated into the coating materials. However, conventional green pigments do not resemble chlorophyll in the infrared region. They absorb infrared light while chlorophyll reflects it. Thus, chlorophyll appears to be the only known organic IR-reflecting pigment; this explains why the shade of trees is cooler than the surrounding area during very hot summer days. As a result, an improperly rendered camouflage colour appears black in contrast to a light-coloured background when viewed with infrared equipment. How do infrared reflective materials (IRR-reflective materials) work? The IRR technology works through visual disruption, caused by the multi-layered infrared signatures for each colour within the print pattern, which have a specific reflective wavelength to blend in with colours in the infrared spectrum for the specific location garments are intended to be worn [7]. The result is greatly reduced visibility of the wearer at night with reflectance to mimic the same wavelengths as snow, rocks, differing urban environments, trees and other green vegetation; while in regular light conditions, you will still have the traditional camouflage patterns to blend into your surroundings [8].

MATERIALS AND METHODS

Layout

Camouflage textile materials were produced using a printing machine with rotating cylinders and inks containing pigments that provide various IR (infrared radiation) shielding levels. The physical-mechanical characteristics of the textile structures Group M are presented in table 1 and table 2, for Group G

Table 1

No.	Characteristics/Variant		UM	M1-A	M2-N	M3-A	M4-N	M5-T
1	Weight		g/m^2	172.66	183.48	229.8	221.28	231.74
2	Density	U	Yarn no./ 10 cm	760	770	500	496	480
		B		270	290	236	240	240
3	Maximum breaking strength	U	N	1443.38	1536.39	1674.34	1708.10	1576.57
		B		1024.20	1100.98	690.02	621.41	652.59
4	Elongation at break	U	%	40.48	45.30	48.08	48.49	47.15
		B		42.63	37.24	14.97	14.61	12.50
5	Resistance to deformation	kPa		726.9	584.7	433	382	387.2
		mm		46.3	36,2	25.0	22.9	23.1
6	Bundle			D2/2	D2/2	D3/1	D3/1	D3/1
7	Water vapour permeability		%	6.3	5.8	30.0	30.8	30.2
8	Air permeability		l/m^2/s	0.0 Impermeable	0.0 Impermeable	258.4	210.1	309.7
9	Abrasion resistance		cycle/no.	>100.000				
10	Fibrous composition		%	69%PA/22%Pes/PU+PTFE		60%Cotton/40%PA		

Table 2

No.	Characteristics/Variant		UM	G1-N	G2-A	G3-T	G4-T	G7-T	G9-A
1	Weight		g/m^2	177.3	178.8	215.1	209.3	151.0	154.1
2	Density	U	Yarn no./ 10 cm	640	640	394	440	614	610
		B		300	300	214	236	292	290
3	Breaking strength	U	N	1191.9	1284.9	1070.1	1289.0	996.2	985.2
		B		779.4	809.7	630.2	990.4	834.4	742.7
4	Elongation at break	U	%	50.3	51.8	13.6	43.1	46.0	44.4
		B		42.3	19.5	14.93	28.2	28.4	-
5	Resistance to deformation		kPa	654.1	746.2	507.5	556.3	679.9	660.2
			mm	44.0	51.4	25.9	27.3	46.9	49.0
6	Bundle			D2/2	D2/2	D3/1	D3/1	D3/1	D3/1
7	Water vapour permeability		%	5.1	5.1	30.4	21.4	2.9	4.0
8	Air permeability		l/m^2/s	8.59	7.93	199.2	153.9	0.0 Imper.	0.0 Imper.
9	Abrasion resistance		cycle/no.	>100000	>100000	70.000 Broken yarns	90.000 Broken yarns	>100000	>100000
10	Fibrous composition		%	80%PA/20%PU		60%Cotton/40%PES		65 %PA+35%PU	

produced by the ST *(Technical specifications)* for Weather Protection Suits (M1, M2, G1, G2, G7, G9) according to ST *(Technical Specification)* 1542/2016 and Combat Suits: (M3, M4, M5, G3) according to ST 1729-2018 for ground forces.

The structures in the M range generate two groups of fibrous compositions: 69%Poliamide/22%Polyester/ Polyurethane + Polytetrafluorethylene) (M1 and M2) with mass ranging from 172.66 g/m^2 (M1) to 183.48 g/m^2 (M2), and 60%Cotton/40%Polyamide (M3-M5) with mass ranging from 221.28 g/m^2 (M4) to 231.74 g/m^2 (M5). The structures in the G range generate three groups of fibrous compositions: 80%PA/ 20%Polyester/Polyurethane (G1 and G2) with mass ranging from 177.3 g/m^2 (G1) to 178.8 g/m^2 (G2), and 60%Cotton/40%Polyester (G3-G4) with mass ranging from 209.3 g/m^2 (G4) to 215.1 g/m^2 (G3), and 65%Polyamide/35%Polyuretane (G7 and G9) with mass ranging from 151.0 g/m^2 (G7) to 154.1 g/m^2 (G9).

ID reflectance

The determination of IR reflectance is a spectrophotometric method used to measure the reflectance on the surface of a flat material (e.g., textile material) as a function of the wavelength of incident IR radiation. IR spectroscopy is a versatile analytical technique that can be applied across a wide range of research and industrial applications. Reflectance is an optical property of the material and represents the ratio (as a percentage) between the intensity of the incident radiation on the surface of the tested material and the total intensity of the radiation reflected in all directions.

Reflection occurs when electromagnetic radiation (e.g., IR) is redirected back into the originating medium after striking the surface of the tested material. This surface separates two different optical media: the first being the source of the incident radiation (air), and the second being the tested material.

One method to measure is 3D Imaging and Light Scattering Techniques that use 3D imaging technology, often combined with lasers or other light sources, to understand how light interacts with a fabric's surface at different angles [9–12].

For textile materials, reflection typically occurs on rough surfaces, which tend to diffuse the radiation, unlike materials with lower roughness.

For such measurements, an integrating sphere is required inside the spectrometer to obtain the reflectance spectrum of the tested surfaces. The equipment used was a UV-VIS-NIR Spectrophotometer, Lambda 950 model, Perkin Elmer, with a spectral range of 185–3300 nm, which includes an integrating sphere unit.

Determination of the proportion of single-colour areas on a multicolour surface

Measuring the optical properties (e.g., reflectance, absorbance) on a multicolour material surface for each colour individually leads to a global characterisation of the material when the measurement results are averaged over a sufficiently large area to be representative of the material under investigation. This is achieved by weighting the values of the measured optical quantities for each colour, thus obtaining a weighted average value that characterises the entire surface of the material in terms of its optical properties. The weights used in this calculation are precisely the contribution weights of the areas of each colour to the total averaging area.

The determination of the average reflectance was carried out using an innovative and original method, consisting of: a) measuring the dimensions and scanning the flat material; b) identifying and indexing the monochromatic areas; c) calibrating the length in the software that calculates the geometric parameters of the objects traced from the images; d) outlining the edges of the region of interest using a closed polyline in the same software, which calculates its area (the value considered as the total area for the subsequent determination of the area weight); e) outlining the edges of each subzone that makes up each monochromatic area using a closed polyline in the same software, except for one monochromatic area to increase processing efficiency; f) calculating the area for the untraced monochromatic zone by subtracting the sum of the other monochromatic areas from the total area; g) determining the weight of each monochromatic zone.

RESULTS AND DISCUSSIONS

Statistical analysis of the variability of the reflection index

To characterise the populations of IR reflection index values in the wavelength range of 860–1200 nm, for each colour and textile structure variant, a specialised program (IBM-SPSS) was used that allowed a rigorous description of the distributions resulting from the tests performed. The mean, variance, standard deviation, median, and quartiles were calculated for the obtained reflection index values, along with skewness and kurtosis to assess asymmetry and highlight cases where interventions might be necessary. The mean, variance, standard deviation, median, and quartiles, along with skewness and kurtosis, are examples of the reflection variable of the colours in the M1 textile structure in table 3. Histograms and box plot graphs of the reflection variable for a colour in the M1 textile structure are shown in figure 1, *a* and *b* (one colour).

From table 3, it can be observed that:

- the skewness indicators for reflexive colours have positive values for light blue (5.514), dark blue (5.486), blue (0.530), indigo (5.451), and green (0.496), which highlights the extent to which the mean deviates from the median. As a result, the normal distribution curves deviate from the centre, shifting to the right;
- the kurtosis indicators show positive values for the colours: light blue (31.465), dark blue (31.219), and indigo (30.904), with the curves being leptokurtic. Negative values are shown for the colours blue (0.836) and green (–1.063), with the curves being platykurtic.

From figure 1, it can be observed that for the colour blue (M1), the reflection variable shows a distribution where 50% of the values are skewed to the left, with the median being positioned towards the lower part of the box. This indicates that lower values of reflection are predominant.

The study of the statistical populations of reflection in the wavelength range of 860–1200 nm highlighted the following aspects for the analysed variants:

- the highest uniformity of reflection values was recorded for variant G3 (ground forces), which contains masking colours of black and shades of grey arranged in regular geometric shapes (rectangle, square, rhombus, etc.);
- the highest non-uniformity of reflection values is presented by variant M5 (ground forces), a combination of khaki, beige, brown, and dark brown colours arranged in irregular shapes; significant non-uniformities of reflection are also presented by variants G7 (ground forces) and M1 (air forces).

To obtain the weighted average value of reflection under the method described above, an example is provided with the steps followed and the corresponding illustrations.

Table 3

REFLECTION VARIABLE OF THE COLOURS IN THE M1 TEXTILE STRUCTURE

Variable		M1 light blue	M1 dark blue	M1 blue	M1 indigo	M1 green
M1	Valid	35	35	35	35	35
	Missing	0	0	0	0	0
Mean		1362.2305	1099.5792	95.5138	1047.8490	93.3396
Std. Error of Mean		926.62797	735.08639	43624	699.75685	56626
Median		62.8588	47.1150	94.5708	44.4902	91.9061
Mode		–34.84*	–12.44*	91.55*	18.06*	89.94*
Std. Deviation		5482.00502	4348.82975	2.58060	4139.81734	3.35005
Variance		30052378.997	18912320.194	6.661	17138087.608	11.223
Skewness		5.514	5.486	530	5.451	496
Std. Error of Skewness		396	396	396	396	396
Kurtosis		31.465	31.219	–838	30.904	–1.063
Std. Error of Kurtosis		778	778	778	778	778
Range		32143.88	25459.51	9.07	24153.63	11.30
Minimum		–34.84	–12.44	91.55	18.06	87.94
Maximum		32109.04	25447.07	100.63	24171.69	99.23
Sum		47678.07	38485.27	3342.98	36674.72	3266.89

Note: *A Multiple mode exists. The smallest value is shown.

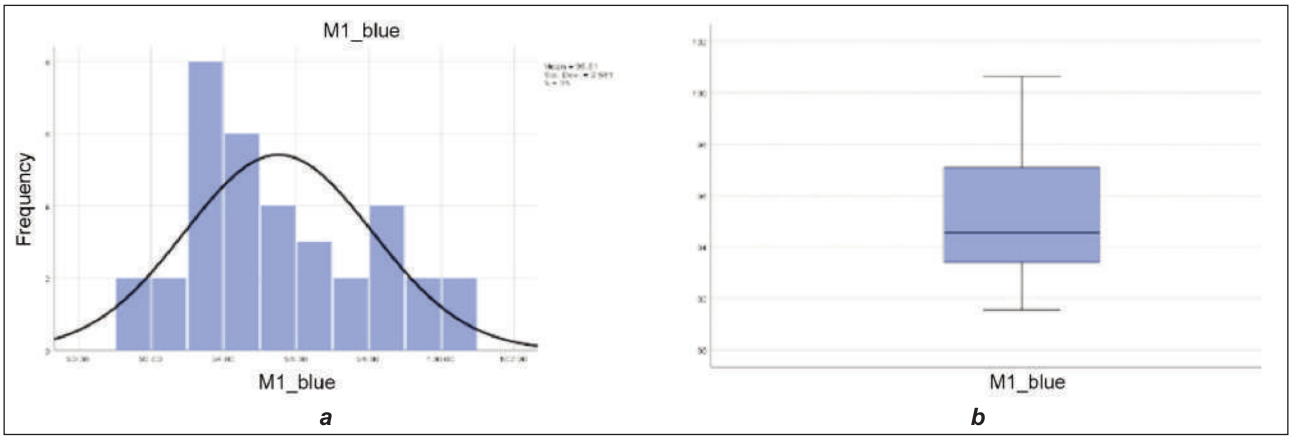

Fig. 1. Graphical representation: *a* – histogram; *b* – box plot graph of the reflection variable (colour variant M1)

Size measurement and scanning

This step allowed the lateral dimensions of 198×175 mm^2 to be identified using a ruler and a flatbed scanner for the material in figure 2, *a* (Scan image of planar material).

Identification and indexing

This step provided the scanned image from figure 2, *b* which illustrates seven colours identified with indices from 1 to 7.

Length calibration

The length calibration was performed; this step consisted of the setting of the correspondence factor between pixel counts and length (11.97 pixels/mm), using the measured size values of the planar material and the same sizes in pixels according to the software. After that, the edge plotting of the entire analysed area was done, providing an image framed into a rectangular boundary (figure 2, *c*). The area of this region was determined (33998.63 mm^2), taking the role of the total area in subsequent weight calculation.

An image with the plot of each subzone of each single-colour zone (exception for colour 5) was obtained (figure 2, *d*), leading to the software measurement of the single-colour areas. The area corresponding to the colour 5 was calculated by subtracting the total area of colours 1, 2, 3, 4, 6 and 7 from the entire analysed area. After that, the contribution ratio of each single-colour zone from the analysed area was

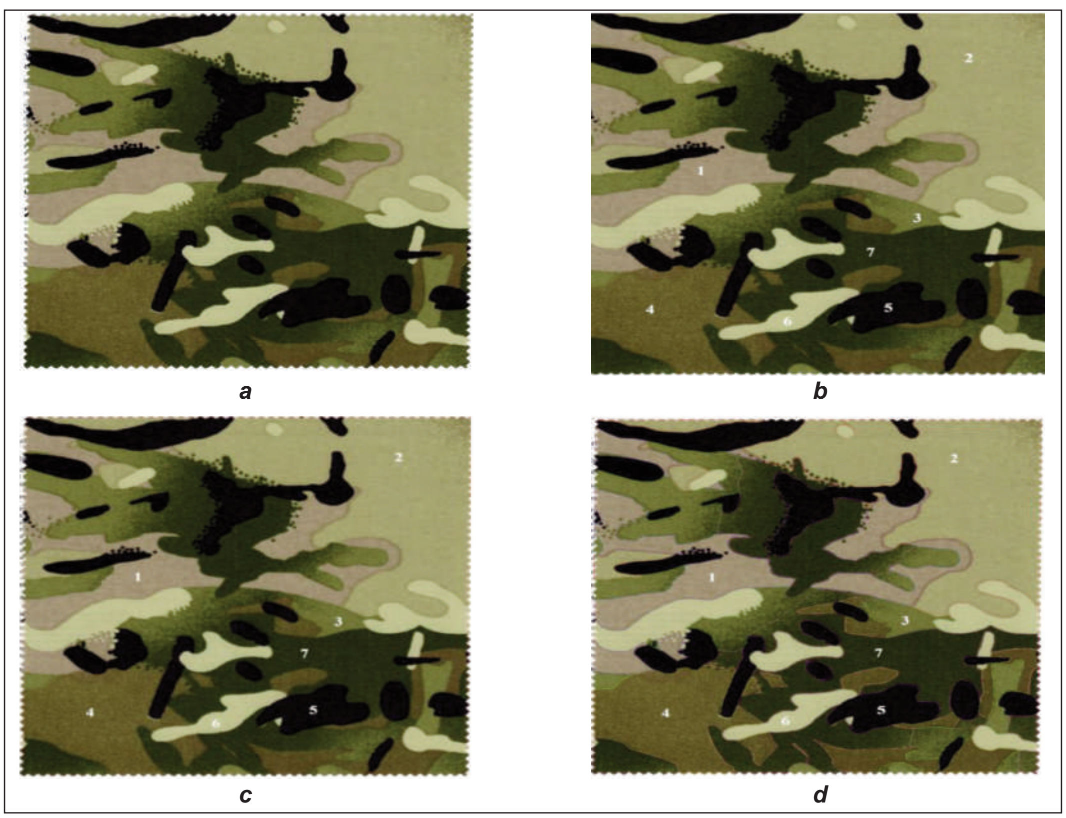

Fig. 2. Photos of: *a* – scan image of planar material; *b* – size measurement and scan; *c* – length calibration and edge plotting of entire analysed area; *d* – edge plotting of each subzone; area calculation for each colour

determined (the ratio of the single-colour area to the total area).

Tracing the region of interest boundary

This step resulted in obtaining the image figure 2, *c* – region of interest bounded by a closed polyline (in red), by tracing the boundary of the region of interest. The area of this region (33,998.63 mm^2) was also generated, considering the total area for the subsequent determination of the weighting. Drawing the boundaries of each subzone and calculating the area for each colour. This step led to obtaining the image (figure 2, *d* – image with each subarea marked with colour) with the graphical representation of each subzone within each monochrome area (except for colour 5).

Additionally, the area values for the monochrome zones were generated by the software after the drawing. The area corresponding to colour 5 was calculated through the subtraction mentioned above.

Determining the weight

This step provided the contribution ratio of each monochrome zone to the area of interest (the ratio between the monochrome area and the total area). The weights are presented in table 4.

Table 4

Monochrome area index	Area (mm^2)	Weight
1	3855.36	0.11
2	6937.39	0.20
3	3932.18	0.12
4	4134.69	0.12
5	5097.54	0.15
6	2751.82	0.08
7	7289.64	0.21

Correlation of reflection indices with the weighting of single-colour areas

To identify the correlation between the reflection indices and the weights of the areas of a single colour, experiments were carried out on the textile structures: M5, G3, G7, G4, G8, M3, G2, G1. Table 5 shows the range of the reflectance of the colours in the spectral band 860 ÷ 1200 nm and the weight of the area covered in the investigated area (%) by each colour for the variants of masking textile structures M1, M3, M5 and G1, G2, G3, G4, G7, G9.

Determination of median values for the reflection index of textile structures

The data series for “Measured Reflection” for each camouflage type was weighted by the percentage of colour coverage in the camouflage pattern of the sample. This resulted in a spectral distribution, also represented graphically, of the reflection coefficients for each camouflage model. Additionally, the regression equations for the data series obtained are displayed on each graph.

For each wavelength, the colour with the lowest reflection coefficient was analysed. From the data series, the frequency of appearance for each colour was calculated, and then the top colours (for all 39 colours) with the lowest reflection coefficient across the entire spectral band were extracted. A similar process was followed for the colours in the second data set, producing the top colours/samples (for the 16 analysed colours) with the lowest reflection coefficient across the entire spectral band.

To assess the reflection degree of each colour across the entire spectral band, the median values were calculated due to the high dispersion of the data. At certain wavelengths, the pigment used has a very strong reflectivity, so the average does not correctly represent the entire spectral band. Therefore, the median value is a much more representative variable of the total reflective qualities. A ranking of the colours based on their reflection index was obtained: black (G3) = –12.0%; brown and dark brown (G7) = 23.52% and 23.46%, respectively; khaki and brown = 32.1% and 32.32% (M5), etc. (figure 3).

Similar to the previous case, the frequency of values was analysed, and a ranking of the types of camouflage analyzed (8 types of camouflage) was obtained, starting with the lowest reflection coefficient recorded for the M5 variant (46.94%), followed by G7 (47.03%) and M3 (53.01%) (figure 4).

Fig. 3. Ranking of the colours

Table 5

DISCRIMINANT VALIDITY (THE FORNELL-LECKER CRITERION)					
Variant	**Colour**	**The colour indicator used in the image of the investigated area**	**Colour reflectance range in the spectral band 860 ÷ 1200 nm (%)**	**Area weight of colour in the investigated area (%)**	**Area covered by colour in the investigated area (pixel²)**
M1	Light blue	M1-a	–34 ÷ 32109	8.98	655697.00
	Dark blue	M1-b	–12 ÷ 25447	28.52	2082281.00
	Blue	M1-c	91 ÷ 100	15.20	1109507
	Indigo	M1-d	18 ÷ 24171	28.27	2064421
	Green	M1-e	87 ÷ 99	19.03	1389346
M3	Dark blue	M3-a	–237 ÷ 180	25.80	1893927.00
	Light blue	M3-b	–4 ÷ 181	4.60	337348
	Indigo	M3-c	–106 ÷ 184	31.18	2288847
	Blue	M3-d	18 ÷ 91	16.69	1225205
	Green	M3-e	–561 ÷ 1303	21.74	1595721
M5	Khaki	M5-a	–17 ÷ 189	31.29	2285608
	Green	M5-b	34 ÷ 291	21.38	1561865
	Beige	M5-c	43 ÷ 103	6.95	507429
	Brown	M5-d	–192 ÷ 1133	19.99	1460095
	Light brown	M5-e	–45 ÷ 36110	20.39	1489485
G1	Black	G1-a	81 ÷ 100	18.44	1452798.00
	Indigo	G1-b	85 ÷ 100	36.33	2862318.00
	Blue	G1-c	89 ÷ 100	5.94	468216.00
	Dark blue	G1-d	85 ÷ 100	20.07	1581624.00
	Light blue	G1-e	89 ÷ 101	19.21	1513701.00
G2	Light blue	G2-a	89 ÷ 101	17.19	1220144.00
	Green	G2-b	84 ÷ 99	34.45	2446195.00
	Indigo	G2-c	85 ÷ 99	16.85	1196675
	Bleu	G2-d	90 ÷ 102	6.63	470458
	Dark bleu	G2-e	86 ÷ 100	24.88	1766544.00
G3	Black	G3-a	–142 ÷ 5251	19.75	1549670.00
	Gray	G3-b	84 ÷ 99	4.59	359999.00
	Light grey	G3-c	90 ÷ 99	15.40	1207997.00
	Dark gray	G3-d	77 ÷ 98	60.26	4727518.00
G4	Beige	G4-a	87 ÷ 99	7.49	514589
	Khaki	G4-b	84 ÷ 99	36.16	2485727
	Light brown	G4-c	–7 ÷ 29000	16.18	1112006
	Dark brown	G4-d	84 ÷ 99	18.25	1254883
	Green	G4-e	–7 ÷ 29000	21.93	1507355
G7	Beige	G7-a	89 ÷ 100	7.27	517592.00
	Brown	G7-b	–43 ÷ 14827	29.92	2129993.00
	Light brown	G7-c	87 ÷ 99	22.46	1598952.00
	Dark brown	G7-d	–58 ÷ 15350	16.21	1153737.00
	Green	G7-e	–1.1 ÷ 22732	24.15	1719336.00
G9	Light blue	G9-a	–12.5 ÷ 85.7	18.93	1361918.00
	Green	G9-b	–35.2 ÷ 86	27.55	1982078.00
	Indigo	G9-c	–50.4 ÷ 112.4	21.03	1512614
	Light blue	G9-d	–2.4 ÷ 1623356.6	7.65	550511
	Dark blue	G9-e	–11.3 ÷ 84	24.84	1786849.00

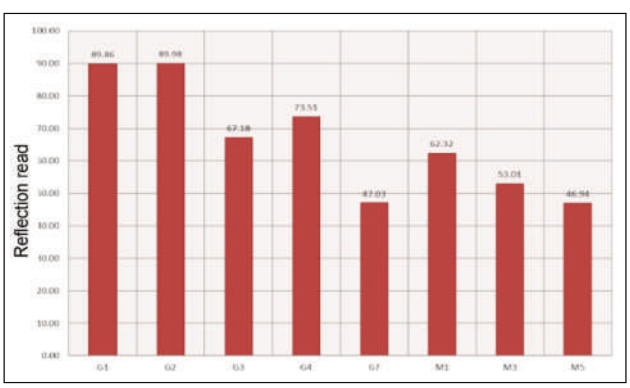

Fig. 4. Measurement model: Reliability

Regression analyses

In figure 5, the initial regression curves are presented, along with the regression curves weighted by the colour areas for the reflection index values at wavelengths from 860 to 1200 nm in 10 nm steps. The linear regression equations with the regression coefficients for the analysed textile structure variants are also shown, which allows the calculation of the regression index as a function of a certain wavelength.

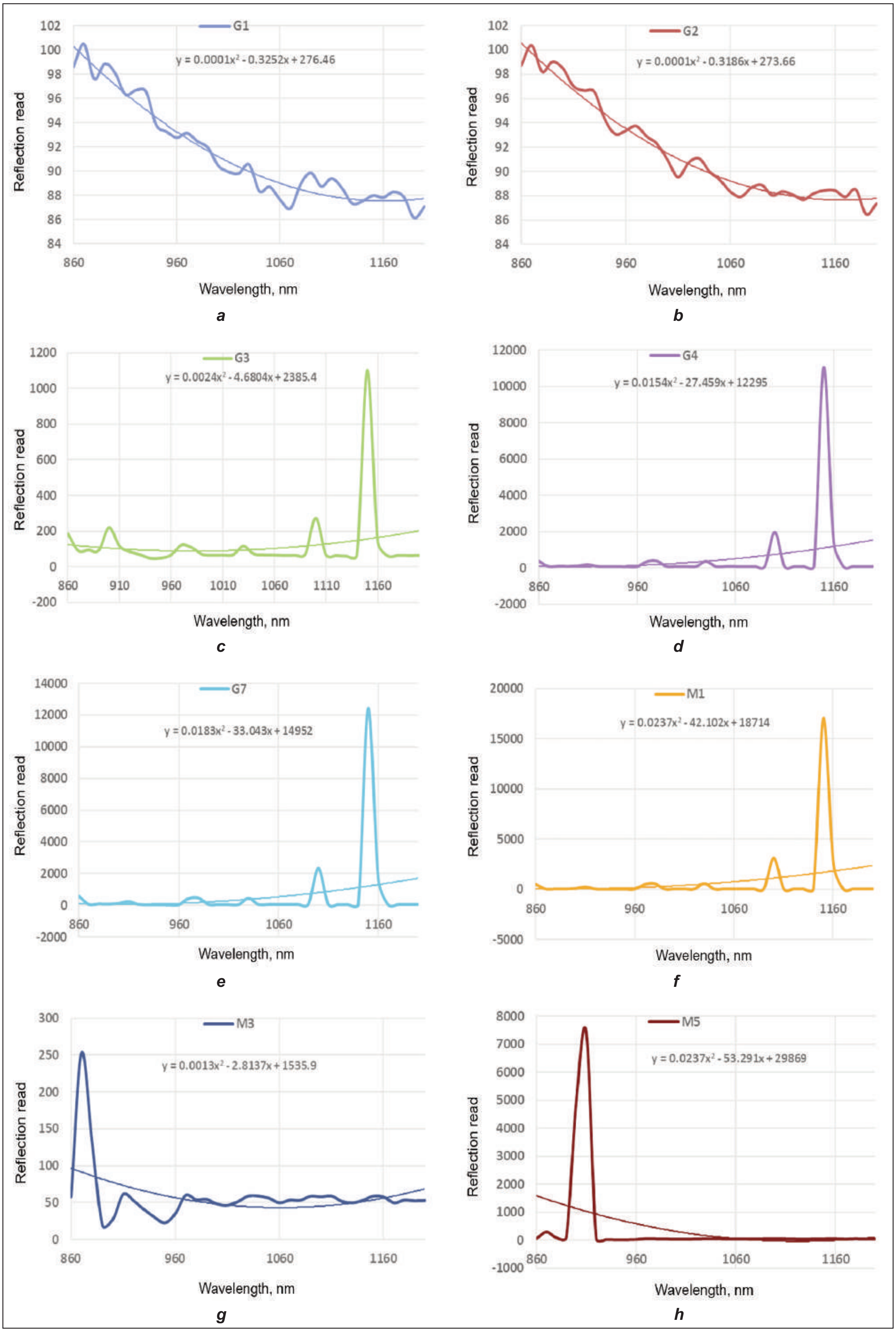

Fig. 5. Regression curves of: *a* – G1; *b* – G2; *c* – G3; *d* – G4; *e* – G7; *f* – M1; *g* – M3; *h* – M5

CONCLUSIONS

Different camouflage variants (M1, M2, M3, M4, M5, G1, G2, G3, G4, G7, G9) with different fibrous compositions, such as a blend of polyamide, polyester, and polyurethane, and with specific properties, such as resistance to abrasion, water vapour permeability, and air permeability are analysed. The determination of IR reflectance is done using a spectrophotometric method, measuring the amount of infrared radiation reflected by the textile material. This helps assess how well the material performs in the IR spectrum, contributing to its effectiveness in camouflage.

The correlation between reflection indices and area weighting for different colours revealed that certain colours, like dark blue and indigo, cover a significant portion of the total area (up to 36% for indigo in the G1 variant). This is important for creating textiles that provide maximum camouflage in both visible and IR spectrums.

The G1 (Ground Forces) variant, with shades like indigo and dark blue, showed a promising combination of high reflectance in the IR range, which can be important for avoiding detection in the infrared spectrum.

The research underlined the importance of designing camouflage patterns that are effective across multiple spectral ranges, especially given the rise of infrared sensors. The textile structures tested showed varying degrees of success in blending into environments when viewed through IR devices, underscoring the necessity for smart textiles to adapt to both visible and infrared camouflage.

Infrared Reflective (IRR) technology, as evidenced in the tests, contributes to reducing visibility in the infrared spectrum by mimicking the natural IR signature of the environment. Materials like khaki and green were found to be more effective in specific environments like forests and urban terrains.

Moving forward, smart textiles that can dynamically adjust to environmental conditions (such as changing colour or insulating properties) will significantly enhance military operations, particularly in covert missions. These adaptive textiles could be designed with further enhancements in their IR reflective properties and resistance to environmental factors.

In conclusion, the study highlights the importance of infrared reflective properties in military camouflage and the critical role of uniformity in reflectance for consistent performance. The findings suggest that a balance between durability, comfort, and effective camouflage across both visible and infrared spectrums is essential for the next generation of military protective textiles.

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Framework for implementing energy efficiency strategies in textile SMEs to achieve sustainability and business growth

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ABSTRACT – REZUMAT

Framework for implementing energy efficiency strategies in textile SMEs to achieve sustainability and business growth

A Small and Medium Enterprise (SME) in the textile industry usually focuses on specialised processes like weaving, knitting, or dyeing while producing and distributing fabrics, clothing or other textile products. This study looks into the sustainability and energy efficiency strategies used by small and medium-sized businesses (SMEs) in Tamil Nadu's textile sector, particularly in manufacturing hubs like Coimbatore, Tiruppur, Madurai and Salem. The study uses a mixed-methods approach combining qualitative information from interviews with SME owners, production managers and sustainability officers with quantitative data obtained from structured questionnaires. A representative sample of 1250 SMEs from a range of industries, including spinning, weaving, dying, and clothing manufacturing, was guaranteed by a stratified random sampling technique. Together with structural equation modelling (SEM), descriptive statistics, correlation analysis and multiple regression analysis were used to analyse the data and investigate the connections between firm performance, sustainability practices and energy efficiency. Three specific hypotheses were examined in this study: how energy efficiency measures affect operational performance, how sustainable practices and financial performance are related and what obstacles exist for the adoption of energy-efficient technologies. The results show strong correlations and gains in financial and operational performance, underscoring the critical role that sustainability and energy efficiency play in raising textile SMEs' competitiveness.

Keywords: *energy efficiency, textile industry, small and medium enterprises, sustainability practices, structural equation modelling, Tamil Nadu*

Cadru pentru punerea în aplicare a strategiilor de eficiență energetică în IMM-urile din industria textilă pentru a obține durabilitate și creștere economică

O întreprindere mică și mijlocie (IMM) din industria textilă se concentrează, de obicei, pe procese specializate precum țeserea, tricotarea sau finisarea, producând și distribuind materiale textile, articole de îmbrăcăminte sau alte produse textile. Acest studiu analizează strategiile de durabilitate și eficiență energetică utilizate de întreprinderile mici și mijlocii (IMM-uri) din sectorul textil din Tmil Nadu, în special în centre de producție precum Coimbatore, Tiruppur, Madurai și Salem. Studiul utilizează o abordare mixtă a metodelor, combinând informații calitative obținute din interviuri cu proprietarii de IMM-uri, managerii de producție și responsabilii cu durabilitatea, cu date cantitative obținute din chestionare structurate. Un eșantion reprezentativ de 1 250 de IMM-uri dintr-o serie de sectoare, inclusiv filatura, țesătoria, finisajul și fabricarea de articole de îmbrăcăminte, a fost garantat printr-o tehnică de eșantionare aleatorie stratificată. Împreună cu modelarea ecuațiilor structurale (SEM), statisticile descriptive, analiza corelațiilor și analiza regresiei multiple au fost utilizate pentru a analiza datele și a investiga legăturile dintre practicile de durabilitate a performanțelor întreprinderilor și eficiența energetică. Trei ipoteze specifice au fost examinate în acest studiu: modul în care măsurile de eficiență energetică afectează performanța operațională, modul în care practicile durabile și performanța financiară sunt legate și ce obstacole există pentru adoptarea tehnologiilor eficiente din punct de vedere energetic. Rezultatele arată corelații puternice și câștiguri în performanța financiară și operațională, subliniind rolul esențial pe care îl joacă durabilitatea și eficiența energetică în creșterea competitivității IMM-urilor din sectorul textil.

Cuvinte-cheie*: eficiență energetică, industria textilă, întreprinderi mici și mijlocii, practici de durabilitate, modelarea ecuațiilor structurale, Tamil Nadu*

INTRODUCTION

The small and medium-sized enterprise (SME) sector plays a crucial role in the global textile industry by fostering innovation, creating jobs, and boosting local economies. Renowned for their adaptability, SMEs can swiftly respond to changing consumer needs, fashion trends, and market dynamics. Their smaller operational footprint allows for the production of specialised products, which helps cultivate customer loyalty. However, SMEs face significant challenges, including difficulty in securing financing, high operating costs, and obstacles in adopting new technologies. As the industry becomes increasingly competitive and environmentally conscious, SMEs are under pressure to implement sustainable practices and energy-efficient technologies. Energy efficiency in the textile sector is achieved by optimising processes like spinning, weaving, and dyeing through advanced machinery, automation, and real-time monitoring. Techniques such as heat recovery, VFDs in motors, and insulation reduce energy waste. Renewable energy integration and ISO 50001 compliance further enhance sustainability, lowering costs and emissions. Initiatives like redesign, upcycling, and cleaner production techniques have emerged as strategies to lower production costs while attracting eco-aware consumers and promoting sustainable growth in the textile sector [1]. Furthermore, effective business planning tailored for textile SMEs ensures market alignment and enhances operational efficiency and profitability [2–4].

Despite their potential, SMEs encounter resource limitations and market competition, which hinder their long-term growth, particularly in sectors like footwear [5]. In regions such as Ekurhuleni, textile SMEs face financial and infrastructure challenges that restrict their innovation capacity [6]. Research in Dhaka's textile manufacturing industry underscores the complex dynamics of sustainable performance, where environmental goals often conflict with financial sustainability, necessitating integrated strategies [7]. Energy efficiency in global textile production is achieved through the optimisation of processes such as spinning, weaving, dyeing, and finishing.

Advanced machinery, such as energy-efficient motors and heat recovery systems, reduces energy consumption. Techniques like low-temperature dyeing, advanced water treatment, and the integration of renewable energy sources further enhance sustainability. Automation and digitalisation also contribute by optimising production workflows and minimising waste. While the adoption of Industry 4.0 technologies can enhance efficiency, many SMEs still struggle with implementing these innovations effectively [8]. Strategic planning is essential for success, as firms with well-defined innovation strategies outperform competitors in challenging markets [9]. By embracing circular economy practices, SMEs can reduce waste, improve product lifecycle management, and close material loops, thereby achieving sustainability [10]. However, a lack of management accounting techniques in emerging markets limits their ability to optimise performance [11]. To thrive amid market volatility, risk management-focused governance frameworks are essential, enabling SMEs to transition towards smart circular supply chains for future success [12, 13]. Sustainable textile waste recycling is increasingly adopting innovative methods like biochemical conversion, thermochemical processes, and mechanical recycling, which improve material recovery rates and reduce environmental impact [14]. In parallel, the textile and fashion industries are integrating circular economy principles, emphasising eco-design, supply chain transparency, and technological advancements to address sustainability gaps and meet evolving environmental regulations [15]. The research questions addressed critical challenges in Tamil Nadu's textile SMEs, focusing on energy efficiency and sustainability to enhance operational and financial performance. By exploring the impact of energy-efficient measures and identifying adoption barriers, the study offered actionable insights for improving competitiveness and environmental compliance. This is crucial for fostering innovation and sustainable growth in the resource-intensive textile sector.

METHODOLOGY

The research methodology involves a structured survey of 1,250 SMEs from Coimbatore, Tiruppur, Madurai, and Salem. Using stratified random sampling, data is collected from SME owners, production managers, and sustainability officers. The study applies Structural Equation Modelling (SEM) for hypothesis testing and utilises descriptive statistics, correlation analysis, and multiple regression to analyse company profiles, energy efficiency, and sustainability practices. The overall research flow was illustrated in figure 1.

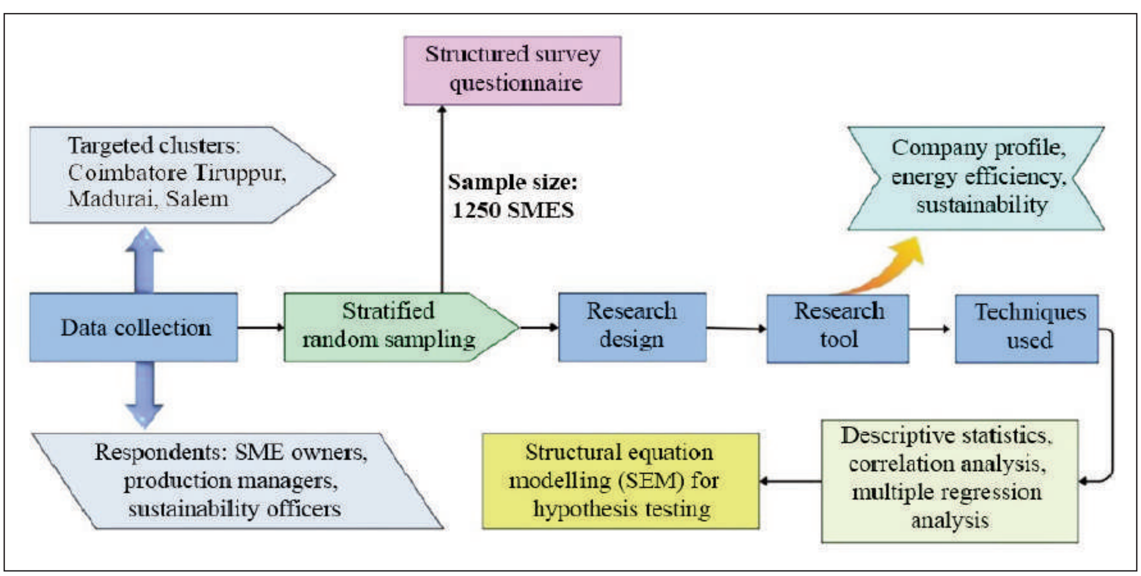

Fig. 1. Research flow

Data collection

This study's data collection process was carried out in manufacturing clusters throughout Tamil Nadu with a focus on cities and industrial hubs known for having a high concentration of small and medium-sized textile enterprises (SMEs). Coimbatore, Tiruppur, Madurai, and Salem are among the clusters chosen for this study. Because of their concentrated textile industries, which are distinguished by their energy-intensive operations, these regions are important. A varied viewpoint on energy efficiency and sustainability practices was ensured by the study's respondents, which included SME owners, production managers and sustainability officers. To guarantee representation from a range of textile industry sectors, a stratified random sampling technique was used. A structured survey questionnaire was used to gather data from 1250 SMEs that made up the sample size.

Research design

This study adopts a descriptive research design to explore the implementation of energy efficiency measures and sustainability practices by SMEs in Tamil Nadu's textile industries. Descriptive research facilitates an understanding of current practices, challenges, and outcomes related to energy efficiency initiatives. Quantitative data was primarily collected through surveys, while qualitative insights were gathered through interviews with selected respondents to provide deeper insights into the barriers to adopting sustainable practices. This mixed-methods approach ensures a comprehensive understanding of the topic.

Research tool

The primary tool for data collection was a structured questionnaire, consisting of three sections they are Company Profile and Demographic Details, Current Energy Efficiency Practices and Challenges, and Sustainability Measures and Environmental Policies. To assess respondents' levels of agreement with various statements regarding energy efficiency and sustainability, a Likert scale ranging from 1 to 5 was utilised, where 1 represented strong disagreement and 5 represented strong agreement. This structured approach enabled a comprehensive evaluation of the company's initiatives, challenges, and overall commitment to sustainability and energy efficiency.

Validity and reliability

To ensure the validity and reliability of the survey instruments, a pre-test was conducted with a small group of SME representatives to refine the questionnaire and eliminate any ambiguities. The content validity was established through expert reviews, ensuring that the items accurately represent sustainability and energy efficiency practices in the textile sector. Reliability was assessed using Cronbach's alpha coefficient, which demonstrated high internal consistency for the survey items. Additionally, factor analysis was employed to confirm the construct validity of the questionnaire, ensuring that all items appropriately measured the intended variables. The combination of these techniques ensures the robustness of the data collected for the study.

Data analysis techniques

Data analysis employed a combination of descriptive statistics, correlation analysis, and multiple regression analysis with ANOVA for hypothesis testing, utilising Structural Equation Modelling (SEM). These methodologies facilitated a comprehensive examination of the interrelationships between energy efficiency, sustainability practices, and firm performance, offering valuable insights into their impact on organisational outcomes.

Correlation Analysis

Correlation analysis evaluates the strength and direction of the relationship between two variables. Correlation analysis provides insights into how energy efficiency practices correlate with sustainability measures, helping identify significant relationships that warrant further exploration.

Multiple regression analysis with ANOVA

Multiple regression analysis assesses the impact of several independent variables on a dependent variable, allowing for a more comprehensive understanding of relationships.

Structural Equation Modelling (SEM)

Structural Equation Modelling (SEM) is a comprehensive statistical technique that facilitates the analysis of complex relationships among variables, encompassing both latent (unobserved) and observed variables. SEM combines elements of factor analysis and multiple regression, allowing researchers to simultaneously assess measurement and structural relationships.

Hypothesis

H1: SMEs in the textile industry implementing energy efficiency measures experience a significant improvement in operational performance.

H2: Adoption of sustainable practices positively impacts the financial performance of textile SMEs in Tamil Nadu.

H3: Lack of access to government incentives is a major barrier to implementing energy-efficient technologies in the textile sector.

RESULTS

Findings of Hypothesis 1

H1: SMEs in the textile industry implementing energy efficiency measures experience a significant improvement in operational performance.

A constant term of 0.235 with a standard error of 0.045 is found by the analysis, which results in a t-statistic of 5.222 and a p-value of 0.000, both of which indicate statistical significance, which is illustrated in figure 2. At a coefficient of 0.182 ($p=0.001$), energy efficiency training has a positive impact on operational performance. Energy-saving technology investment has a significant positive impact, as indicated by its coefficient of 0.275 ($p=0.000$).

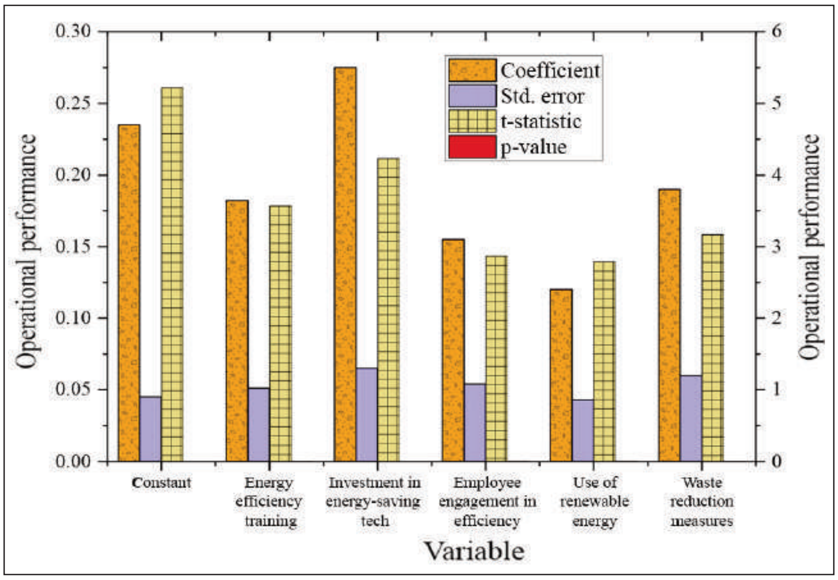

Fig. 2. Operational performance of the textile industry

A constant of 0.305 with a standard error of 0.055 is revealed by the financial performance multiple regression analysis, which is illustrated in figure 3. A significant positive impact on financial performance is demonstrated by the coefficient of 0.29 (p=0.000) for the adoption of sustainable practices. A coefficient of 0.225 (p=0.000) indicates that cost savings from sustainable dyeing also contribute. Greater brand reputation has a coefficient of 0.19 (p=0.001), whereas the increased demand for eco-friendly fabric has a coefficient of 0.165 (p=0.001). Gaining access to green certifications has a coefficient of 0.25 (p=0.000) while the growth in market share for sustainable products correlates at 0.22 (p=0.001). With a coefficient of 0.18 (p=0.000), employee satisfaction with sustainable practices is the last factor that positively contributes.

A coefficient of 0.155 (p=0.005) suggests that employee engagement also has a positive impact on results. Furthermore, waste reduction strategies have a coefficient of 0.19 (p=0.002), whereas the use of renewable energy contributes with a coefficient of 0.12 (p=0.006). Product quality improvement and supply chain efficiency both have significant contributions to operational performance as evidenced by their respective coefficients of 0.145 (p=0.004) and 0.213 (p=0.001).

Statistical significance is demonstrated by the F-statistic of 5.672 and the p-value of 0.000. With 95 degrees of freedom and a mean square of 1.497, the sum of squares within groups is 142.235, which adds up to 187.905 overall.

The following variables show significant positive correlations: the use of renewable energy sources has a correlation coefficient of 0.367 (p=0.020), employee engagement in energy efficiency is correlated at 0.48 (p=0.005), and investment in energy-saving machinery has a correlation coefficient of 0.682 (p=0.000). The correlation between waste reduction measures in dyeing and supply chain efficiency in yarn production is 0.491 (p=0.003) and 0.514 (p=0.002). Finally, there are significant positive correlations as evidenced by the correlation coefficient of 0.405 (p=0.010) for the improvement in fabric quality.

The ANOVA about the improvement of financial performance reveals a mean square of 13.033, a between-groups sum of squares of 52.13, and 4 degrees of freedom. Statistical significance is indicated by an F-statistic of 6.932 and a p-value of 0.000. There is 206.335 overall because the within-groups sum of squares is 154.205.

Strong relationships can be seen in the cost savings from dyeing (0.590, p=0.000) increased demand for eco-friendly fabric (0.680, p=0.000) enhanced brand reputation (0.545, p=0.001) increase in market share (0.610, p=0.000) green certifications (0.580, p=0.002) and employee satisfaction (0.450, p=0.005).

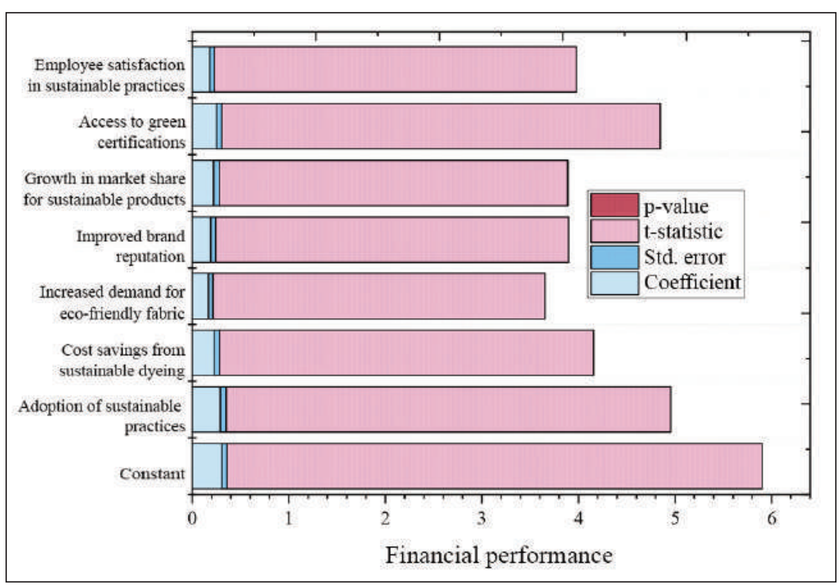

Fig. 3. Influence of sustainability factors on financial performance

Findings of hypothesis 2

H2: Adoption of sustainable practices positively impacts the financial performance of textile SMEs in Tamil Nadu.

Findings of hypothesis 3

H3: Lack of access to government incentives is a major barrier to implementing energy-efficient technologies in the textile sector.

A constant of 0.402 with a standard error of 0.052 is found in the multiple regression analysis for the obstacles to adopting energy-efficient technologies, which is described in figure 4.

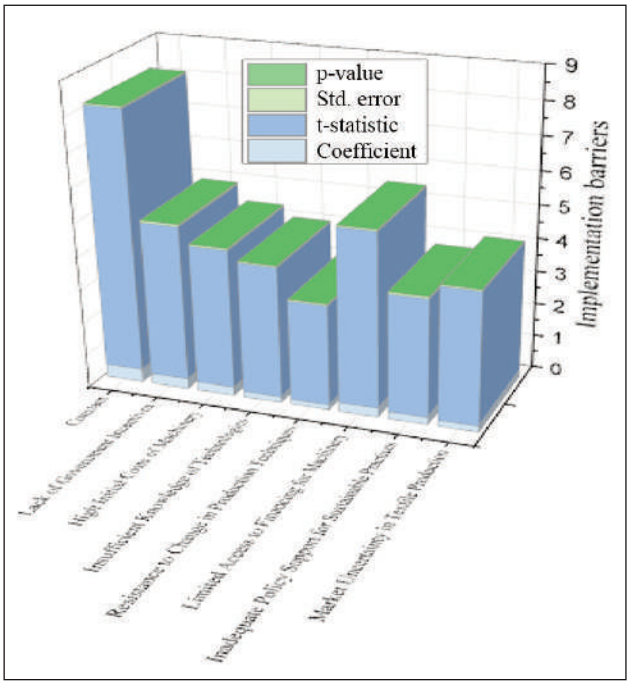

Fig. 4. Analysis of contributing factors to implementation resistance

With a coefficient of 0.31 (p=0.000), the absence of government incentives has a major effect on implementation. High machinery startup costs have a 0.265 coefficient (p=0.000). The market uncertainty in textile production (0.19, p=0.000), lack of policy support for sustainable practices (0.225, p=0.001), resistance to changing production methods (0.15, p=0.003), restricted access to financing for machinery (0.275, p=0.000), and a lack of technological knowledge (0.18, p=0.000) are additional factors.

With a p-value of 0.000 and an F-statistic of 7.125, these values indicate statistical significance. A total of 143.000 is generated by the within-group sum of squares, which is 105.440.

The study reveals several barriers to implementation including high initial investment costs (0.680, p=0.000) insufficient knowledge and skills (0.620 p=0.001) market competition (0.590 p=0.002) uncertainty in policy changes (0.570 p=0.003) limited access to financial resources (0.500, p=0.005) employee resistance to change (0.540 p=0.004) and lack of awareness of sustainable practices (0.450 p=0.006).

STRUCTURAL EQUATION MODELLING

To assess the connections between the different elements influencing sustainable performance in textile SMEs in Tamil Nadu, this study makes use of structural equation modelling or SEM which is explained clearly in figure 5. Energy Efficiency Measures (EEM), Operational Performance (OP), Sustainable Practices (SP), Government Incentives (GI), and Financial Performance (FP) are the five latent variables that make up the model. H3 illustrates the connection between Energy Efficiency Measures (EEM) and Government Incentives (GI). According to this hypothesis, being able to access government incentives has a positive effect on the adoption of energy-efficient practices, including resource management (RM), process optimisation (PO), and energy-saving practices (ESP). It is hypothesised that the Energy Efficiency Measures (EEM) variable affects Operational Performance (OP) represented as H1, which comprises metrics such as operational outcomes (OO), cost reduction (CR) and productivity improvement (PI). The purpose

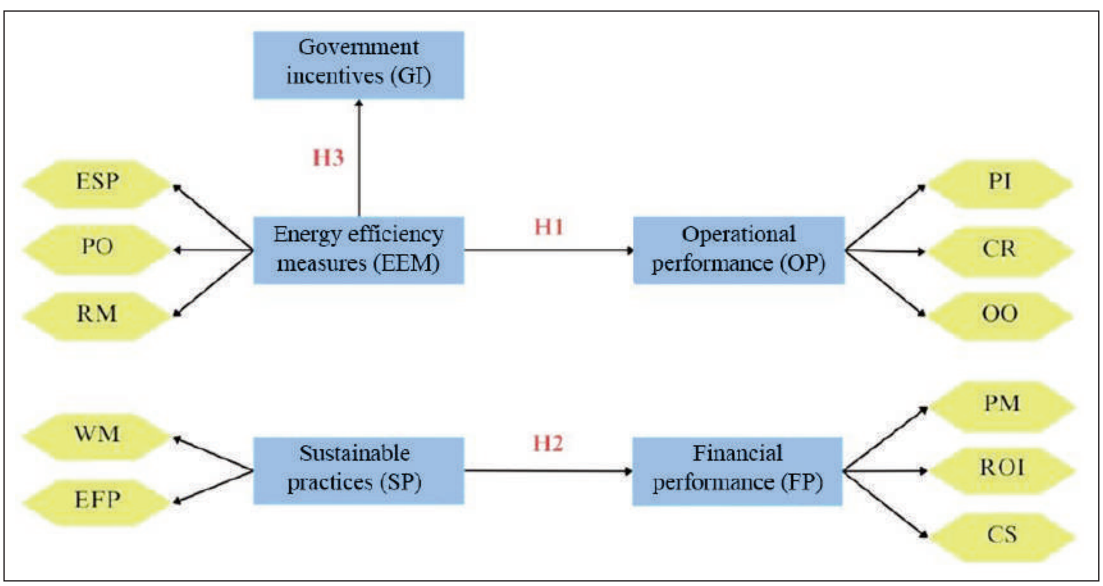

Fig. 5. SEM model

of this relationship is to illustrate how operational performance can be improved through energy-efficient measures.

The influence of Sustainable Practices (SP) on Financial Performance (FP) is examined in another relationship, H2. Waste management (WM) and eco-friendly production (EFP) are two components of sustainable practices that support financial indicators like cost savings (CS), ROI and profit margins (PM). The impact of government assistance, energy conservation, and sustainable practices on the financial and operational results of textile SMEs can be evaluated both directly and indirectly with the use of this model. Businesses in the textile industry can improve their operational and financial aspects by utilising SEM to understand the causal relationships between these constructs and how energy management, sustainability initiatives and government policies interact.

IMPLICATIONS

The findings on energy efficiency in the textile industry hold significant implications for stakeholders, including manufacturers, policymakers, and investors. Manufacturers can leverage optimised processes and advanced technologies to reduce operational costs, enhance productivity, and meet sustainability goals. Policymakers gain insights to shape regulations promoting green practices, while investors can identify opportunities in sustainable innovations. Collectively, these findings drive competitiveness, compliance with global standards, and long-term environmental and economic benefits for the industry. Textile SME managers can adopt energy-efficient strategies such as upgrading to energy-efficient machinery, implementing heat recovery systems, and using real-time energy monitoring tools. These measures can significantly reduce operational costs, improve resource utilisation, and enhance overall competitiveness while meeting sustainability goals.

CONCLUSION

This study highlights the critical importance of sustainability practices and energy efficiency in enhancing the operational and financial performance of small and medium-sized enterprises (SMEs) in Tamil Nadu's textile sector. SMEs adopting energy-efficient practices reported an average productivity increase of 18%, and those prioritising sustainability experienced a 12% higher profit margin. This demonstrates that investments in energy-efficient technologies are not just ethically sound but also financially advantageous. The analysis revealed that energy efficiency measures positively impacted operational performance with coefficients of 0.182 (p=0.001) for training, 0.275 (p=0.000) for technology investment, and 0.155 (p=0.005) for employee engagement.

Sustainable practices significantly improved financial performance, with coefficients of 0.29 (p=0.000) for adoption and 0.225 (p=0.000) for cost savings in dyeing. Barriers like lack of government incentives (coefficient = 0.31, p=0.000) and high machinery costs (coefficient = 0.265, p=0.000) were significant. SEM analysis showed positive relationships between energy efficiency, sustainable practices, and both operational and financial outcomes. However, the study also identified significant obstacles, such as limited access to technology and financial resources, hindering SMEs' implementation of energy efficiency measures. Addressing these challenges is essential for fostering a more sustainable textile sector. Policymakers can facilitate this transition by implementing incentives and support programs, potentially achieving a cumulative energy savings of around 20%. The findings underscore the need for a commitment to sustainability and energy efficiency for the long-term resilience and competitiveness of the industry. This study is subject to certain limitations, such as its reliance on self-reported data, which may introduce bias, and its geographic focus on Tamil Nadu, limiting generalizability to broader contexts. Additionally, the cross-sectional design does not capture the long-term impacts of sustainability practices. Future research could explore longitudinal analyses, expand to other regions, and investigate the role of emerging technologies like AI and IoT in enhancing energy efficiency and sustainability. These directions would deepen understanding and provide more comprehensive insights for the textile industry.

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INFORMATION FOR AUTHORS

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Tables and figures (diagrams, schemes, and photographs) shall be clear and color, where possible.

The photographs shall be sent in original format (their soft), or in JPEG or TIF format, having a resolution of at least **300 dpi**.

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Generally, symbols and abbreviations shall be used according to ISO 31: Specifications for quantities, units and symbols. SI units must be used, or at least given comprehensive explanations or their equivalent.

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[1] Hong, Y., Bruniaux, P., Zhang, J., Liu, K., Dong, M., Chen, Y., *Application of 3D-to-2D garment design for atypical morphology: a design case for physically disabled people with scoliosis*, In: Industria Textila, 2018, 69, 1, 59–64, http://doi.org/10.35530/IT.069.01.1377

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