VLÁKNA a TEXTIL

FIBRES AND TEXTILES

2
Volume 32
April
2025

TECHNICAL UNIVERSITY OF LIBEREC

STU FCHPT

Trenčianska univerzita Alexandra Dubčeka v Trenčíne
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RESEARCH INSTITUTE OF TEXTILE CHEMISTRY
VÝSKUMNÝ ÚSTAV TEXTILNEJ CHÉMIE

CHEMOSVIT FIBROCHEM

VÚCHV

ZSVTS

Indexed in:
SCOPUS
Chemical Abstract
World Textile Abstracts
EBSCO Essentials

ISSN 1335-0617
print version

ISSN 2585-8890
online version

VLÁKNA A TEXTIL
http://www.vat.ft.tul.cz

PUBLISHED BY
Technical University of Liberec, Faculty of Textile Engineering
Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology
Alexander Dubček University of Trenčín, Faculty of Industrial Technologies
Slovak Society of Industrial Chemistry, Bratislava
Research Institute of Man-Made Fibres, JSC, Svit
Research Institute of Textile Chemistry (VUTCH) Ltd., Žilina
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PUBLISHER
Technical University of Liberec
Studentska 1402/2, 461 17 Liberec 1, CZ
Tel: +420 485 353615
e-mail: vat@tul.cz
IČO: 46747885

ORDER AND ADVERTISEMENT OF THE JOURNAL
Technical University of Liberec
Faculty of Textile Engineering
Studentska 1402/2, 461 17 Liberec 1, CZ
Tel: +420 485 353615
e-mail: vat@tul.cz

TYPESET AND PRINT
Polygrafie TUL, Voroněžská 1329/13, 460 01 Liberec 1, CZ

DATE OF ISSUE
March 2025

APPROVED BY
Rector's Office of Technical University of Liberec
Ref. no. RE 17/25, 15th April 2025

EDITION
First

PUBLICATION NUMBER
55-017-25

PUBLICATION
Quarterly

SUBSCRIPTION
60 EUR

REG. NO. MK ČR E 24338

VLÁKNA A TEXTIL
Volume 32, Issue 2, April 2025

CONTENT

EFFECTS OF LIGHT SOURCES ON ILLUMINANCE DIFFERENCE AND COLOR DIFFERENCE FOR DYED FABRICS

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ABSTRACT

Under various light sources, the color of dyed fabrics could be observed in different ways. In this study, the red (R), green (G) and blue (B) dyed fabrics were evaluated through color difference (ΔE) and illuminance difference (ΔI) under daylight (D65), fluorescence (F, TL84, CWF), and ultraviolet (UV) lights. It was found that when D65, a standard daylight illuminant, is used as the reference, ΔE value under TL84 and CWF light sources was not significantly different. Therefore, D65 can be complemented by TL84 and CWF for color evaluation to enhance accuracy. The study also highlighted that using a 45-degree viewing angle yielded the most objective color evaluation results. This angle provides optimal conditions for observing light reflection, contributing to more reliable color evaluation. Additionally, dye concentration had a significant impact on color evaluation. An incorrect dye concentration can alter the ability of fabric to absorb light, leading to inaccurate evaluations. Furthermore, washing cycles also affect the colorfastness of dyed fabrics, with increased washing leading to a brighter appearance and higher light reflection.

KEYWORDS

Light source; Color Fabric; Color difference (ΔE); Illuminance Difference (ΔI); RGB Histogram.

INTRODUCTION

In textile production, color consistency is a crucial factor in ensuring product quality and meeting consumer expectations [1,2]. Color plays a significant role in influencing customer perception, particularly in sectors such as apparel, home furnishings, and technical textiles [3-5]. With the growing demands of global markets, ensuring consistent color standards during manufacturing has become more critical than ever [6]. Color evaluation is essential in industries such as textiles, fashion, automotive, and paint manufacturing, where accurate color representation is critical for quality control, product consistency, and customer satisfaction

In general, color evaluation is carried out through a range of methods, from simple visual assessments to advanced instrumental techniques. Modern tools like spectrophotometers and colorimeters provide precise measurements, yet optical methods continue to hold value in ensuring color consistency across various production stages [7-13]. In fact, factors like light sources, observation angles, dye concentration, and washing cycles can significantly influence color evaluation results [14,15].

Despite technological advancements, ensuring uniformity remains a challenge in textile color evaluation, particularly under varying lighting and observation conditions [16,17]. Inconsistent results can lead to products that fail to meet customer expectations, negatively impacting a brand's reputation [1,18,19]. Understanding the effects of external factors like light source, dye concentration, and washing is critical for manufacturers aiming to improve production quality.

Light sources, especially LED light, play an important role in determining the appearance of colors and ensuring color consistency across various fabrics and products [20,21]. The perception of color can change drastically depending on the type of light used, making it important to choose the right lighting conditions for accurate color evaluation. Furthermore, textile evaluation under different lighting also helps assess the color fastness properties of dyed fabrics, particularly their resistance to fading or changing color by washing and ultraviolet exposing conditions [22,23].

Light sources have different color temperatures (measured in Kelvin), which impact the way colors are perceived [24]. Daylight (D65) provides a balanced light source for color evaluation, while cool white fluorescent (CWF) light can make colors appear cooler, often with a bluish tint. Fluorescent light, commonly used in retail stores, typically has a color

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Received October 17, 2024; accepted January 21, 2025

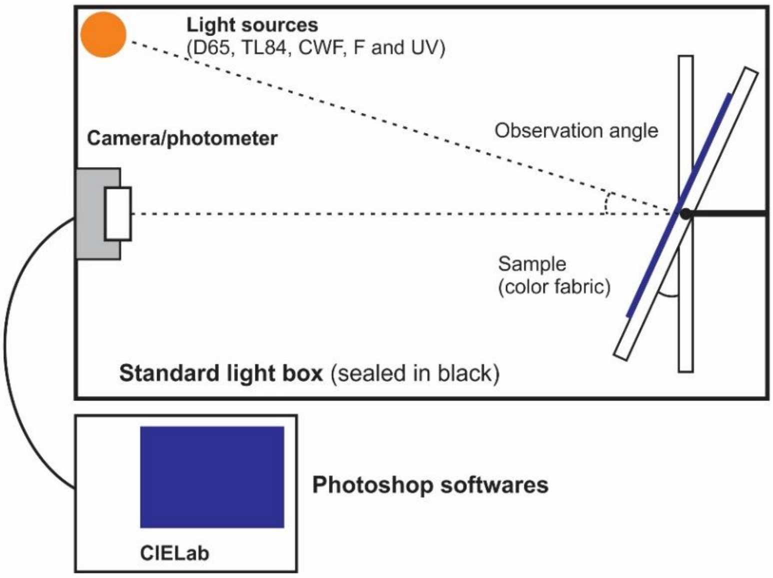


Figure 1. Standard light box setup with five light sources (D65, TL84, CWF, F and UV).

temperature of around 4,000K. Fabrics with fluorescent dyes or finishes may appear brighter or change color under ultraviolet (UV) light due to their ability to absorb UV radiation and re-emit it as visible light. The intensity of the light source, or illuminance (measured in lux), can also influence color perception [25,26]. The brightness and clarity of colors improve with high illuminance, but this may amplify the contrast between subtle shades. Conversely, low illuminance can cause colors to appear darker and less vibrant, making it harder to differentiate between various shades.

This research examines key factors influencing the optical evaluation of dyed fabrics, including light sources, observation angles, dye concentrations, and washing conditions. By analyzing their interactions and effects on illuminance and color differences, the study proposes optimized conditions to reduce discrepancies in color assessments. It also explores how repeated washing cycles impact fabric appearance. The findings aim to offer practical recommendations for textile manufacturers to enhance color consistency and reliability, while minimizing waste and resource consumption. Additionally, these insights can guide future research on dyeing techniques and color evaluation.

MATERIALS AND METHODS

This study used three types of woven fabrics, each dyed with specific colorants and characterized by their respective color indices in the CIE color space, to achieve consistent and uniform red, green, and blue colors. Each fabric sample was cut into squares of equal size (10 cm×10 cm). The fabric samples were conditioned under standard conditions (23°C, 65% RH) for 24 hours prior to testing to ensure stable measurements. Each sample was placed under a light source in the light box for a fixed period to simulate real-world viewing conditions. In this study, five following light sources were used including 1) **D65** (daylight) - a standard daylight illuminant used to simulate natural sunlight which it serves as the reference light source for accurate color evaluation, 2) **TL84** (fluorescent) - commonly used in retail environments, 3) **CWF** (cool white fluorescent) - primarily used in retail spaces, 4) **F** (fluorescent) - widely used in settings where color evaluation and visual consistency are important in textile and fashion showrooms, and 5) **UV** (ultraviolet) - invisible to the human eye but has a significant impact on certain materials (e.g., textiles).

A standard light box with different light sources (D65, TL84, CWF, F and UV) was used to simulate the lighting conditions for color evaluation (as illustrated in Figure 1). A photometer (Reed Instrument, R8130 light meter) was used to measure the illuminance in lux and the difference in illuminance (ΔI) was determined as follows:

$$\Delta \boldsymbol{I} = |\boldsymbol{I_D} - \boldsymbol{I_S}| \quad (1)$$

where I_D is the illuminance of the sample under D65 light, and I_S is the illuminance of the samples under other lights.

A camera is installed in the light box and connected with a computer. The photoshop CS2 software is used to determine the three coordinates (L^*, a^*, b^*) of captured photos according to the CIELab color space under lighting conditions. The color difference (ΔE^*) represents the color distance between samples and is calculated as follows:

$$\Delta \boldsymbol{E}^* = \sqrt{(\Delta \boldsymbol{L}^*)^2 + (\Delta \boldsymbol{a}^*)^2 + (\Delta \boldsymbol{b}^*)^2} \quad (2)$$

Table 1. Illuminance difference (*ΔI*) and color difference (*ΔE*) of red, green, blue fabrics under D65, F, TL84, UV and CWF lights.

Light source	Red		Green		Blue	
	ΔI	**ΔE**	**ΔI**	**ΔE**	**ΔI**	**ΔE**
D65	-	-	-	-	-	-
F	5.5	33.5	2.8	36.3	20.6	67.1
TL84	**23.1**	17.8	0.7	28.1	8.9	36.4
UV	**94.4**	58.0	74.9	12.3	87.3	28.6
CWF	6.0	15.8	7.6	15.8	17.3	32.3

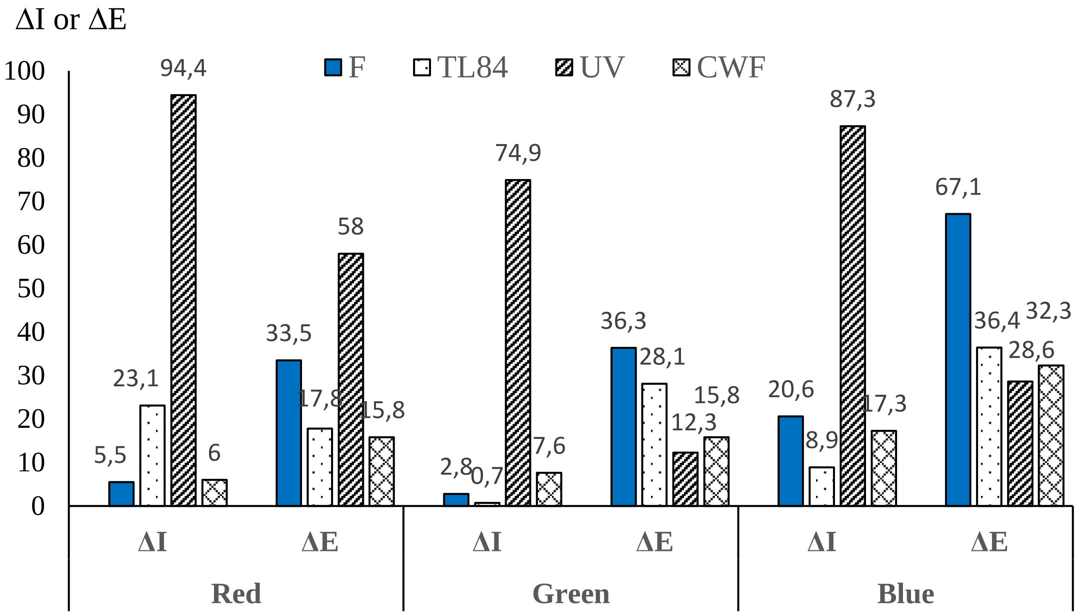


Figure 2. Comparison of illuminance and color difference between red, green and blue fabrics under F, TL84, UV and CWF lights.

where ΔL^*, Δa^*, and Δb^* are the differences in lightness, the green-red axis, the blue-yellow axis between two colors, respectively.

MATLAB software was also utilized to display the spectral reflectance curves, enabling comparisons of sample photos captured at different observation angles under various light sources. Finally, the blue-dyed twill denim fabric was tested using a Miele washing machine (in accordance with ISO 105-C06) to simulate real-world evaluations of color differences under different lighting conditions.

RESULTS AND DISCUSSION

Effects of light source on illuminance difference and color difference

Light sources remarkably impact on the perception of color in dyed fabrics which is a critical aspect of color evaluation in textile industry. Different light sources can change the fabric appearances, leading to varying degrees of illuminance and color difference, as displayed in Figure 2 and Table 1.

The illuminance of dyed fabrics varied with different light sources. D65, which mimics natural daylight, provided the most accurate reflection of the fabric colors, offering the highest illuminance values for all fabric samples. This is because D65 provides a full spectrum of light, allowing true colors of fabrics to be revealed. Under TL84 and CWF lights, *ΔI* value decreased slightly, especially for red fabrics (i.e., 23.1 and 6.0) and blue fabrics (i.e., 8.9 and 32.3). This demonstrates that these artificial light sources do not offer the same color-rendering capability as natural daylight, leading to a reduced perception of luminous intensity. However, the reduction was not large enough to significantly affect the overall visual quality of the fabrics under typical retail lighting conditions.

The *ΔE* values, which measure the color difference between a standard sample (under D65 light) and the sample under various light conditions, were also influenced by the type of light source. It showed that while TL84 and CWF light sources led to measurable color differences, the *ΔE* values remained within acceptable limits for retail and general use in the textiles and fashion ($\Delta E \leq 3.0 - 5.0$, according to ASTM D3136). Red fabrics showed the highest ΔE values, particularly under CWF lighting, indicating that red colors are more sensitive to changes in light sources. Blue fabrics, on the other hand, exhibited relatively lower *ΔE* values, suggesting that blue colors are more stable across different lighting conditions. The green fabric showed moderate *ΔE* values under both TL84 and CWF light sources, indicating that while there is a noticeable shift in color, it is not as significant as the shift of red fabric.

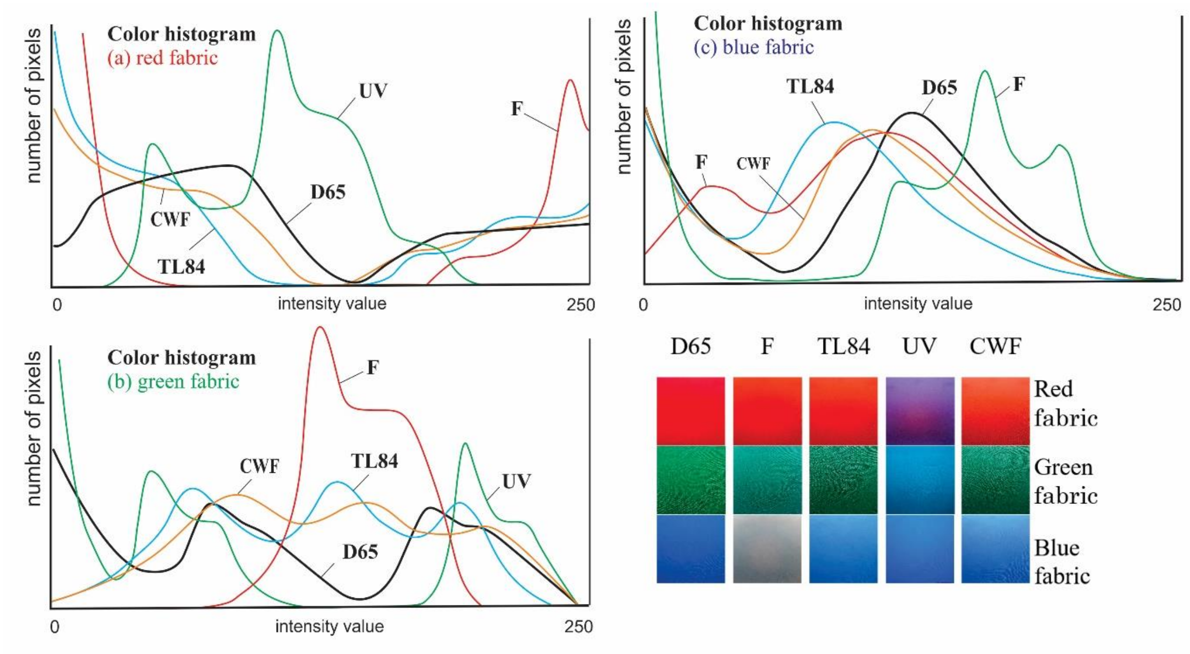
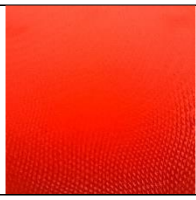
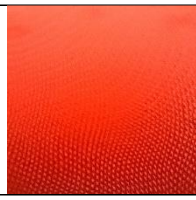
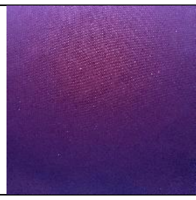


Figure 3. Color histogram of red, green, and blue fabrics (RGB images) under D65, F, TL84, UV and CWF lights.

Table 2. Illuminance difference (ΔI) and color difference (ΔE) of red fabrics with observation angles of 45°, 60° and 75° under D65, F, TL84, UV and CWF lights.

Observed angle	**D65**	**F**	**TL84**	**UV**	**CWF**
45°					
ΔI	-	5.5	23.1	94.4	6.0
ΔE	-	33.5	17.8	58.0	15.8
60°					
ΔI	-	3.7	16.2	72.6	13.8
ΔE	-	46.5	37.6	42.0	31.5
75°					
ΔI	-	0.9	2.0	39.3	15.5
ΔE	-	33.8	26.6	61.8	13.1

Based on color histogram (as shown in Figure 3), the energy distribution curves can reveal the effect of light sources on color perception. Accordingly, different light sources can change the color perception for dyed fabrics. Light sources with uneven energy distribution, such as F and TL84, can distort color perception, while the D65 light source is the ideal reference as it simulates natural sunlight, providing more accurate color reproduction.

It can see that F curves present strong emission in short and long wavelength region but no emission in middle wavelength region (yellow and green), making them appear "cooler" or "harsher" compared to natural daylight.

Effects of observation angles on color accuracy of dyed fabrics

The results in Table 2 indicated that the observation angle had a noticeable effect on the accuracy of color evaluation for red, green, and blue fabrics. Specifically, as the observation angle shifted from 45° to 60° and 75°, there was a corresponding change in both *ΔI* and *ΔE*. For all three fabric colors, the optimal viewing angle for achieving the most accurate and reliable color evaluation was found to be 45°. At this angle, the fabrics reflected light in a manner that provided the most consistent and true representation of their actual colors.

As shown in Figure 4, the spectral reflectance curves of red fabrics depict their reflectance behavior under various light sources (D65, F, UV, CWF, and TL84) and observation angles (45°, 60°, and 75°). The curves are analyzed across the blue region (400–500 nm), green region (500–600 nm), and red region (600–700 nm), with the highest reflectance observed in the red region, consistent with the red appearance of fabrics.

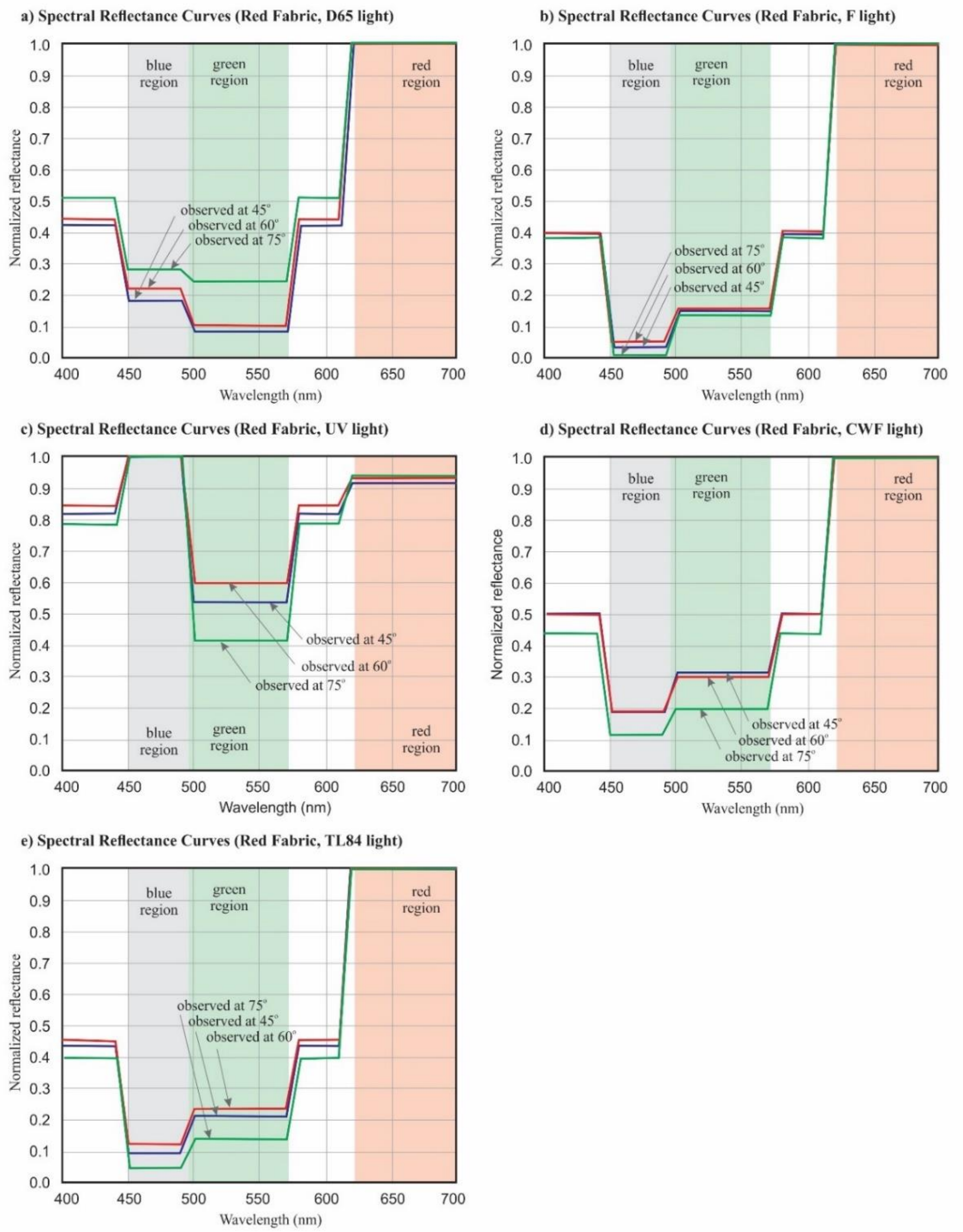
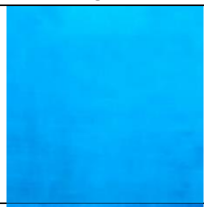
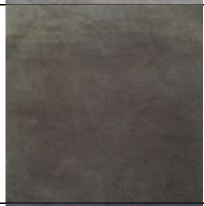


Figure 4. Spectral reflectance curves of red fabrics under a) D65, b) F, c) UV, d) CWF, and e) TLT84 light sources at 45, 60 and 75º of observation angle.

Table 3. Photos of fabrics dyed with 1, 3, and 6wt% of indigo pigment under D65, F, TL84, UV and CWF lights.

Sample	D65	F	TL84	UV	CWF
SP01 (1%)					
SP03 (3%)					
SP06 (6%)					

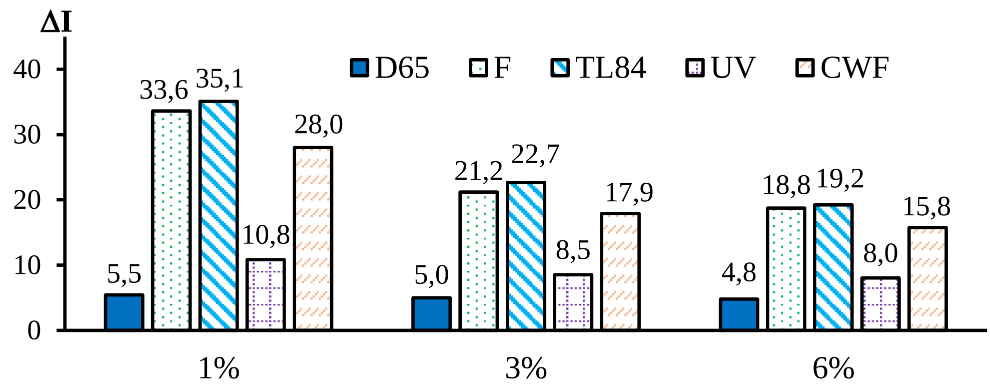


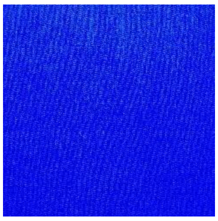
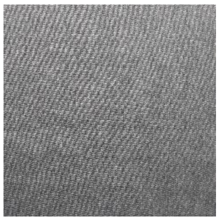
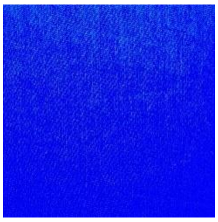
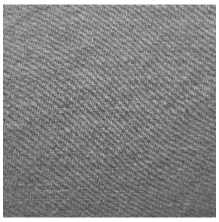
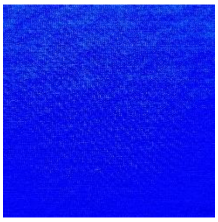
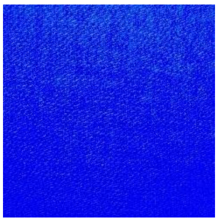
Figure 5. Difference in illuminance of fabrics dyed with 1, 3, and 6 % of indigo dyes under D65, F, TL84, UV and CWF lights.

Across all light sources, slight variations in reflectance are observed with changes in observation angles, indicating minor angular dependence. Under D65 light, reflectance is highest in the red region but decreases slightly at larger observation angles. For F light, red reflectance remains dominant, but the green and blue regions exhibit a sharper decline, with noticeable angular variations in the green region. In UV light, a peak appears in the blue region due to UV sensitivity, accompanied by slight spectral shifts across angles. CWF light shows a similar pattern to F light but with smoother transitions between the green and red regions, and less pronounced angular effects. Finally, TL84 light demonstrates smoother reflectance transitions, with dominant red reflectance and minimal angular dependence. Obviously, the observation angle has a minor but noticeable impact on the spectral reflectance of dyed fabric under different light sources.

Effects of observation angles on color accuracy of dyed fabrics

Table 3 and Figure 5 indicate that the dye concentration significantly influences the color intensity of blue fabrics. Accordingly, increasing dye concentration consistently led to a decrease in the ΔI value across all light sources (D65, F, TL84, UV, and CWF), suggesting that more dye particles are absorbed by the fibers, resulting in deeper and more intense colors. It reflects the basic principle that higher dye concentrations allow for greater dye uptake, thereby enhancing color intensity. Nevertheless, beyond a certain threshold, the increase in ΔI value begins to plateau, indicating a saturation point, where occurs when the fiber has absorbed as much dye as it can, and additional dye in the solution no longer contributes to significantly deeper colors. This plateau suggests a maximum dye absorption limit, after which the ΔI value remains relatively stable despite further increases in dye concentration. The results align with the theory of equilibrium dyeing, where the dye-fiber interaction reaches its peak, and the fabric can no longer take up more dye molecules.

Table 4. The ΔE values of blue denim fabrics after 0, 3, 6 and 9 washing cycles under D65, F, TL84, UV and CWF lights.

Washing cycle	**D65**	**F**	**TL84**	**UV**	**CWF**
0					
ΔE	-	45.3	42.8	86.9	43.4
3					
ΔE	-	46.5	43.7	78.2	44.6
6					
ΔE	-	45.8	44.0	95.7	43.9
9					
ΔE	-	42.8	40.2	100.4	40.4

As shown in Table 4, the *ΔE* values decreased with each washing cycle, indicating a loss in color intensity and the leaching of dye molecules from the fabric. Notably, higher *ΔE* values were more pronounced under UV light, measuring 86.9, 78.2, 95.7, and 100.4 after 0, 3, 6, and 9 washing cycles, respectively. This can be attributed to repeated exposure to washing, particularly under alkaline conditions, which causes dye molecules to desorb from the fibers, leading to color fading. Fabrics dyed with lower dye concentrations were more susceptible to fading during washing, likely due to weaker dye-fiber interactions. In contrast, fabrics dyed with higher dye concentrations exhibited better color retention after multiple washing cycles, possibly because of stronger or more abundant dye-fiber bonds.

CONCLUSION

This research highlights the significant impact of light sources on the color measurements of dyed fabrics, with particular emphasis on illuminance color and color difference under different lighting conditions. The study demonstrated that D65 and TL84 offer the most consistent and accurate color rendering, especially for green fabrics, while F and UV lights tend to distort color perception, particularly in the red and blue channels. Moreover, the stability of perceived color with varying observation angles is affected by the light source, with D65 and F lights showing more noticeable changes, while TL84 exhibits the most consistent reflectance across angles. These findings are essential for textile manufacturers aiming to maintain color consistency in their products, particularly when viewed under different lighting environments such as retail stores, homes, and outdoor settings. By optimizing evaluation conditions and considering the influence of light sources, manufacturers can improve quality control, reduce color discrepancies, and ensure that products meet consumer expectations. This research provides a foundation for future studies on textile color evaluation and its practical applications.

Acknowledgement: *This work belongs to the project in 2025 funded by Ho Chi Minh City University of Technology and Education, Vietnam.*

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EMERGING TRENDS IN THE USE OF IMMERSIVE TECHNOLOGIES FOR GARMENT DESIGN

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ABSTRACT

This study examines the applications of immersive technologies, such as virtual reality (VR) and augmented reality (AR), in apparel design. The aim is to identify current trends, advancements, gaps and opportunities for future research. A review of the literature has identified that these technologies enable designers to create digital prototypes, optimise creative processes and reduce material waste, thereby contributing to greater sustainability and efficiency in the fashion industry. However, research in this field demonstrates considerable fragmentation, which presents a challenge in integrating these advances into a coherent conceptual framework. While the adoption of AR and VR has grown, the implementation of advanced technologies such as artificial intelligence and machine learning remains limited. Furthermore, although sustainability is a relevant topic, it has not been sufficiently analysed in terms of its social and environmental impact. This study highlights the need for a more integrated approach and government support to encourage the ethical and responsible adoption of these technologies.

KEYWORDS

Immersive Technologies; Apparel design; Virtual reality; Augmented reality; Sustainability.

INTRODUCTION

The advent of immersive technologies, such as virtual reality (VR) and augmented reality (AR), has brought about a transformation in various industries, including fashion. These digital tools facilitate the generation of three-dimensional experiences that modify the design, prototyping, and marketing of clothing. In the field of textile design, these technologies facilitate the visualisation of designs in digital environments prior to their manufacture, thereby optimising both creative and production processes [1], [2].

In the field of fashion, these technologies provide innovative and sustainable solutions. The use of AR enables designers to collaborate in virtual environments, thereby reducing the necessity for physical samples and the subsequent material waste [3]. Conversely, VR is employed to simulate virtual catwalks and create immersive experiences for consumers, thereby eliminating geographical barriers and promoting accessibility [2].

The utilisation of these technologies enhances the efficiency of design processes by facilitating expedient and precise adjustments in real time. Furthermore, it encourages creativity by providing an array of tools to experiment with textures, colours, and shapes in an unlimited manner [4]. Consequently, immersive technologies transform the field of apparel design, while fostering a sustainable approach that is aligned with the current demands of the industry [5].

The research literature on the applications of immersive technologies in apparel design exhibits a notable degree of fragmentation, which presents a challenge in developing a consolidated conceptual structure. The absence of a unified framework that synthesizes the most salient advances impedes a comprehensive understanding of the subject and constrains the development of coherent lines of

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Received January 22, 2025; accepted February 11, 2025

research. While there are studies that explore specific aspects, such as the application of VR and AR to textile design, these have not been integrated into a systematic approach that allows for a comprehensive understanding of the subject [6], [7].

RQ1: What has been the evolution of the number of publications per year in this field?

RQ2: Who are the most influential authors and journals in this field?

RQ3: What are the most cited studies in research on immersive technologies applied to textile design?

RQ4: How are scientific publications on this topic geographically distributed?

RQ5: What are the emerging, growing and decreasing keywords in this field?

The originality of this study lies in its innovative approach, which proposes a new structure for the scientific body on immersive technologies applied to clothing design. This is achieved through an exhaustive analysis of the existing literature. This work updates the existing knowledge in a rapidly evolving field, identifying the emerging trends and gaps in research. By establishing a clear research agenda, guided by the advances and challenges identified, this study makes a significant contribution to the consolidation of a scientific framework that allows for a more comprehensive understanding of textile design with immersive technologies. This, in turn, paves the way for future explorations and the development of new solutions for the industry.

METODOLOGY

The methodology employed in this research is based on the PRISMA 2020 protocol, an updated guide for conducting systematic literature reviews [10]. This approach was selected for its capacity to facilitate a comprehensive and transparent analysis of the extant evidence pertaining to the applications of immersive technologies in apparel design. The utilisation of PRISMA guarantees the incorporation of pertinent sources and offers a unified and comprehensive perspective on the present state of the subject matter, whilst minimising potential biases in the review process, thus ensuring the dependability and validity of the outcomes obtained [11].

Eligibility criteria

The review included studies that addressed the application of immersive technologies, including VR, AR, mixed reality (MR), and related technologies (such as XR) in apparel design. Only studies of an academic nature, including systematic reviews and empirical research, were considered. To ensure the reliability of the findings, studies must be without time specificity and have access to the full text. The exclusion process was divided into three phases. The first phase excluded articles with errors in the indexing metadata. The second phase eliminated documents without access to the full text. The third phase discarded those that did not directly address the application of immersive technologies in apparel design or that lacked practical implications in this field.

Sources of information

The research employed two databases, namely Scopus and Web of Science, which are widely acknowledged for their comprehensive coverage and high quality in the retrieval of scientific literature [12]. The Scopus database was selected for its extensive coverage of areas such as engineering, technology, and applied sciences, making it a key source for accessing articles on technological innovations in textile design. In contrast, Web of Science is renowned for its multidisciplinary database, which encompasses high-impact articles across a range of disciplines, including engineering and design. This makes it a valuable supplementary resource for acquiring pertinent insights on the utilisation of immersive technologies. The databases permit precise searches and access to high-quality articles, thereby ensuring the comprehensiveness of the review [13].

Search strategy

The search strategy was designed for each database with a structured equation that included key terms on apparel design and immersive technologies, such as "augmented reality", "virtual reality", "immersive technologies", "mixed reality" and "extended reality", along with the combination of terms such as "textile design", "immersive technologies", "fashion design" and "apparel design". This search was performed on key metadata such as title and keywords. This strategy was derived from the established inclusion criteria, ensuring that the search focused on published articles on the use of immersive technologies in apparel design.

Selection process

The selection process was conducted in several stages, as illustrated in Figure 1, which presents a comprehensive flowchart. First, searches were conducted in Scopus and Web of Science, employing the established inclusion and exclusion criteria. Subsequently, the titles and abstracts of the retrieved articles were evaluated to ascertain their relevance. Then, the full texts of the studies that passed the initial screening were analysed to confirm their compliance with the defined criteria. Finally, the selected studies were included in the systematic review, ensuring their quality and relevance to the research topic.

Data processing

The data were processed using Microsoft Excel, which is a standard tool for the management and analysis of large volumes of information. Following the selection of pertinent studies, the essential data

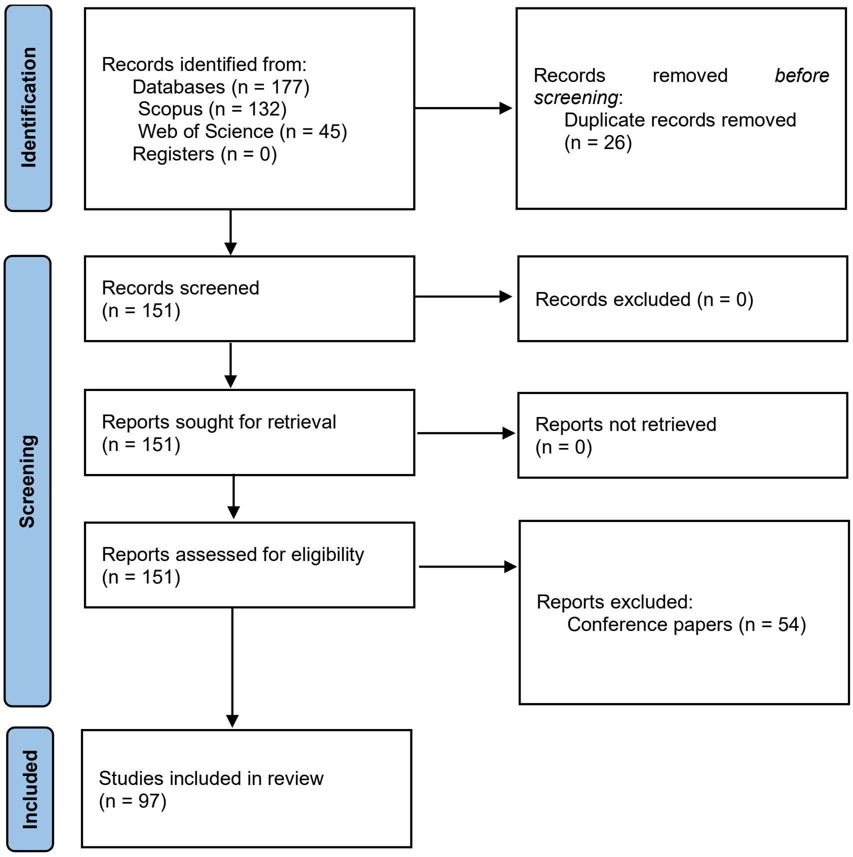

Figure 1. PRISMA flowchart. Own elaboration based on Scopus and Web of Science.

from each article were extracted, including the year of publication, the authors, the immersive technologies employed, the principal conclusions, and the areas of application in textile design. The data were subsequently organised in spreadsheets, thus facilitating their categorisation and comparative analysis. The Microsoft Excel software facilitated the efficient manipulation of data, as well as the visualisation of trends over time and the identification of research gaps and opportunities.

Risk of bias

The potential for bias in this study was mitigated through a meticulous process of article selection and evaluation, in accordance with the PRISMA 2020 protocol. In order to mitigate publication bias, two large and recognised databases were utilised. The databases Scopus and Web of Science were used to access a wide variety of studies, both in terms of authors and sources. However, the exclusive use of these databases and specific terms could have introduced biases, thereby limiting the scope of the search and excluding relevant studies from other sources or approaches. Furthermore, the potential for reporting bias was taken into account, as some studies may not have been published due to the absence of statistically significant results or editorial considerations.

RESULTS

The scientific literature on the applications of immersive technologies in apparel design dates back to 1996 and spans until 2024, demonstrating exponential growth with a coefficient of determination (R^2) of 0.9951, as illustrated in Figure 2. This value indicates a strong correlation between time and the increase in the volume of publications, thereby suggesting a stable and predictable trend. In recent years, there has been a notable increase in scientific production, with 13 articles published in 2021, 16 in 2022, 9 in 2023, and 14 in 2024. These findings underscore the mounting interest in the incorporation of immersive technologies into textile innovation, thereby reinforcing this domain as a pivotal focus for academic inquiry and industrial advancement.

The analysis of the principal authors in the field of immersive technologies applied to clothing design permitted the identification of three distinct groups, as illustrated in Figure 3. The first group, represented in orange, comprises authors with a high impact in terms of publications and citations. However, no authors were identified in this category. The second group, indicated in blue, comprises authors with a limited number of publications but a high number of citations relative to the average. This group is composed of the following authors: Boissieux, Cani, Wither, Cho and Kim, among others. The third group,

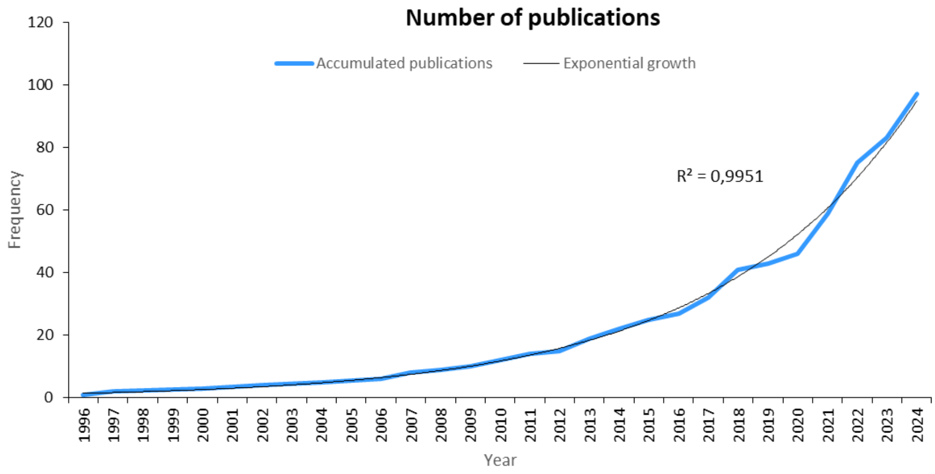

Figure 2. Evolution of the number of publications.

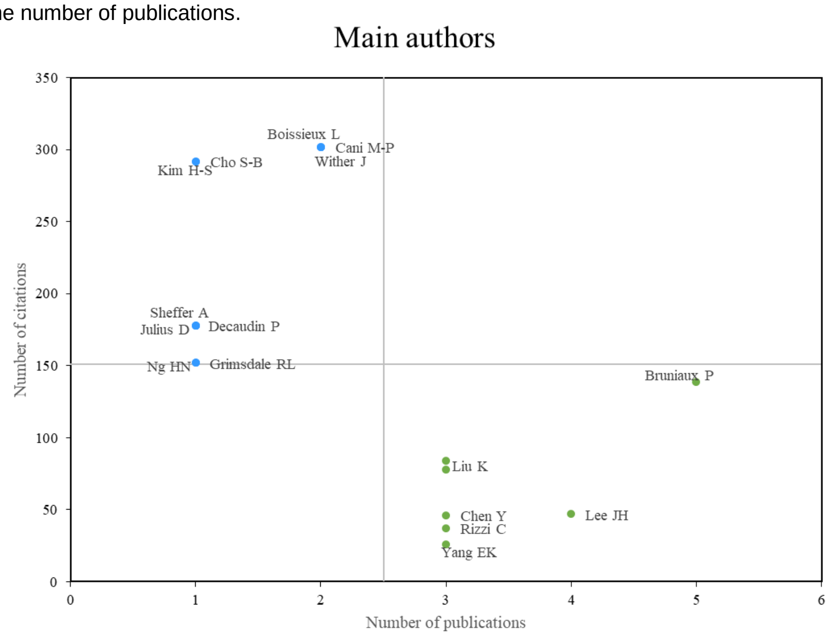

Figure 3. Main authors.

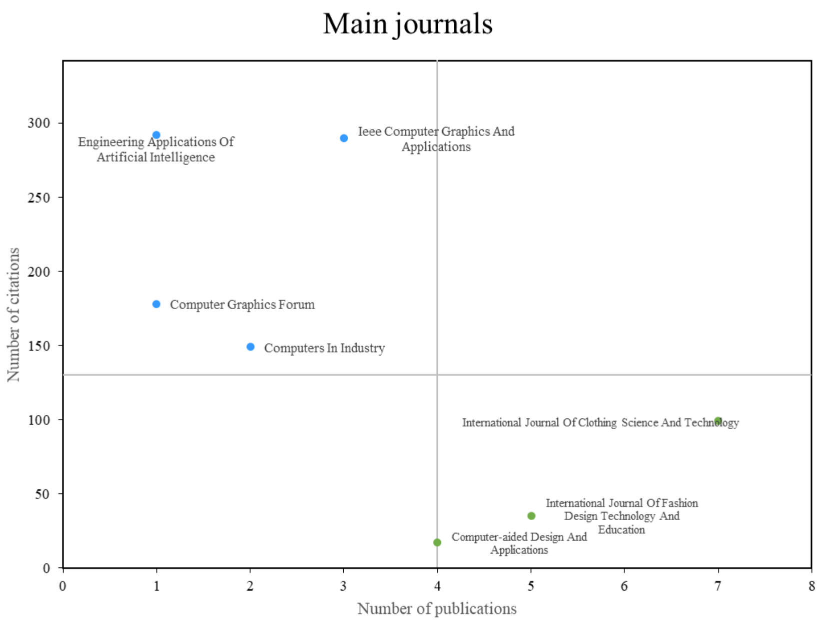

Figure 4. Main journals.

represented in green, comprises authors who have demonstrated high academic productivity, albeit with a relatively limited number of citations. This group comprises Bruniaux, Lee, Liu, Chen, Rizzi and Yang, who have made a significant contribution to the advancement of this field.

Moreover, an analysis of the principal journals in the field of immersive technologies applied to apparel design revealed the existence of three distinct groups, as illustrated in Figure 4. The first group, represented in orange, corresponds to journals with a high impact in terms of publications and citations. However, no journals were identified within this category. The second group, indicated in blue, comprises journals with a relatively low number of publications but a high number of citations in comparison to the average. These include IEEE Computer Graphics and Applications, Engineering Applications of Artificial Intelligence, Computer Graphics Forum and Computers in Industry. The third group, represented in green, corresponds to journals with high academic productivity, but with a low number of citations. In this group, the International Journal of Fashion Design Technology and Education, as the main representative, and Computer-Aided Design and Applications stand out.

This research presents an analysis of the ten most cited articles on the application of immersive technologies to the field of clothing design, as compiled in Table 1. The most notable studies are those of Kim and Cho [14], who applied an interactive genetic algorithm to fashion design, with 292 citations, and those of Decaudin et al. [15], who developed virtual garments. A Fully Geometric Approach for Clothing Design by Decaudin et al[15] is another notable study, with 178 citations and high academic impact. Other relevant works include Computer graphics techniques for modelling cloth by Ng and Grimsdale [16], with 152 citations; A survey on CAD methods in 3D garment design by Liu et al. [17], with 142 citations; and A sketch-based interface for clothing virtual characters by Turquin et al. [18], with 124 citations. Furthermore, recent contributions are examined, including Elfeky and Elbyaly's [19] "Developing skills of fashion design by augmented reality technology in higher education" and Hong et al.'s [20] "Design and evaluation of personalized garment block for atypical morphology using the knowledge-supported virtual simulation method," which illustrate the evolution and diversity of approaches in this field of study.

The global distribution of research on the applications of immersive technologies for clothing design, as illustrated in Figure 5, reveals a notable concentration in a few countries. China is the most prolific country in this field, with 40 publications, followed by South Korea with 9 and the United States with 7.

Other countries with lower production are Portugal (4), France (3), India (3), Hong Kong (3), Italy (3), Switzerland (2) and Canada (2). At the continental level, Asia is identified as the primary driver of this field, with notable contributions from China, South Korea, India, and Hong Kong. Europe also plays **a** significant role, with notable contributions from

Table 1. Main contributions in the literature

Title	Authors	Citations
Application of interactive genetic algorithm to fashion design	[14]	292
Virtual garments: A fully geometric approach for clothing design	[15]	178
Computer graphics techniques for modeling cloth	[16]	152
A survey on CAD methods in 3D garment design	[17]	142
A sketch-based interface for clothing virtual characters	[18]	124
A template of ease allowance for garments based on a 3D reverse methodology	[21]	61
Virtual reality-based collaborative design method for designing customized garment for disabled people	[22]	46
Developing skills of fashion design by augmented reality technology in higher education	[19]	41
Exploring the nature of digital transformation in the fashion industry: opportunities for supply chains, business models, and sustainability-oriented innovations	[23]	31
Design and evaluation of personalized garment block for atypical morphology using the knowledge-supported virtual simulation method	[20]	25

Figure 5. Global distribution.

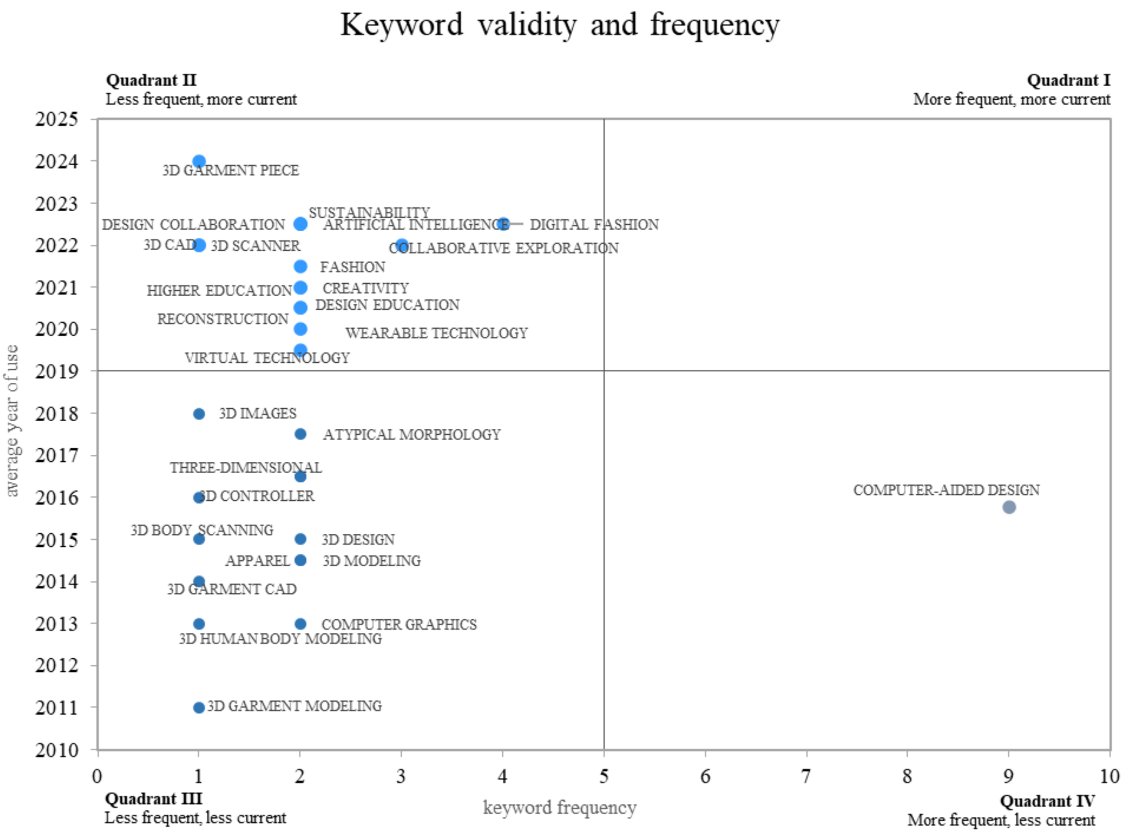

Figure 6. Main keywords.

Portugal, France, Italy and Switzerland. In the Americas, the United States and Canada are the predominant contributors, while other regions demonstrate minimal or no engagement in this field. This illustrates an uneven geographical distribution, with Asia and Europe being the predominant regions.

Furthermore, a scatter graph was constructed to analyse the keywords associated with the utilisation of immersive technologies in the domain of clothing design. This is illustrated in Figure 6. The graph depicts the average year of use of the keywords on the y-axis and their frequency of appearance on the x-axis. This allows for the concepts to be classified according to their temporal relevance and level of research. Keywords situated in Quadrant 1 are characterised by a high level of recent research activity and usage, which demonstrates their current relevance. The second quadrant encompasses emerging concepts, which exhibit a lower frequency of use but a recent average year of appearance, indicative of substantial growth potential. Keywords in Quadrant 4 are those that have been widely researched but whose average year of use is less recent, suggesting a possible shift towards other approaches.

The results demonstrate that no keywords were identified in quadrant 1, indicating the absence of concepts that exhibit both high frequency and timeliness. The second quadrant comprises emerging terms of interest, including 3D garment piece, sustainability, artificial intelligence, digital fashion and design collaboration, and others. These terms have recently emerged as relevant in the field. Keywords such as computer-aided design are identified in the fourth quadrant. Despite extensive previous research, this term shows a lower level of timeliness compared to more recent terms.

DISCUSSION

The discussion of this research is organised into several sections with the objective of offering a comprehensive analysis of the applications of immersive technologies in the design of clothing. Firstly, the results obtained are subjected to analysis and structured in a conceptual framework that facilitates their understanding. Secondly, they are compared with other relevant studies in order to identify similarities and differences. Thirdly, the existing gaps in the research are subjected to analysis, followed by a proposal for a future research agenda. Finally, the theoretical, practical and political implications, as well as the limitations of the study, are discussed.

Analysis of results

Theoretical development in the applications of immersive technologies in apparel design has undergone a remarkable evolution since 1996. In its nascent stages, research, as exemplified by Ng and Grimsdale [16], concentrated on fabric modelling techniques, with an emphasis on technical and visual aspects pertaining to geometric and physical precision. As the literature has grown at an accelerated pace in recent years, the approach has begun to incorporate consumer behaviour. More recent research, such as that of Lin, Li, and Xia [24], employs a psychological lens to examine the influence of factors such as novelty and sociability on consumer intent to purchase virtual garments. This shift reflects a transition from a technical approach to an analysis of the interaction between the consumer and digital fashion.

A review of the literature reveals three distinct groups of authors who have made significant contributions to the field of immersive technologies applied to apparel design. The initial group, which combines both high production and high impact, is not represented by any authors in this study. The second group comprises Boissieux, Cani, Wither, Cho and Kim, who, despite having a relatively limited publication history, have a high citation impact. These authors have made notable contributions to the field of virtual garment design, particularly in the areas of physical simulation of clothing and 3D modelling [15]. The third group comprises Bruniaux, Lee, Liu, Chen, Rizzi and Yang, who have a high level of academic productivity, though their work has not yet achieved a significant impact in terms of citations. Nevertheless, their research, including that related to 3D modelling of garment fit parameters [25], continues to contribute to the advancement of virtual design models and customisation.

Similarly, an analysis of the principal journals on immersive technologies in apparel design reveals the existence of three distinct groups. The second group comprises journals such as IEEE Computer Graphics and Applications, which, despite a relatively low number of publications, has a high citation impact. This journal has been instrumental in the advancement of interactive interfaces for garment creation, as evidenced by a system that determines the shape and fit of garments to virtual characters using distances between the 2D silhouette and the 3D model [18]. The third group, characterised by high productivity but fewer citations, is represented by the International Journal of Clothing Science and Technology. This journal has developed a virtual reality-based method for designing customised garments for individuals with scoliosis, adapting the two-dimensional design to three-dimensional form [22].

The articles by Kim and Cho [14] and Decaudin et al. [15] represent seminal contributions to the field of immersive technologies applied to garment design. In their 2000 article, Kim and Cho introduced the concept of interactive genetic algorithms (IGAs) for the design of garments. By incorporating human response into the design process, they were able to overcome the limitations of traditional methods and facilitate adaptation to the ever-changing landscape of fashion. In 2006, Decaudin et al. proposed an intuitive system that converts 2D sketches into realistic 3D patterns, thereby generating developable surfaces for the creation of precise sewing patterns. Both studies are seminal in the evolution of digital fashion, integrating immersive technologies into the domain of garment design and enhancing interactivity and customisation.

Conversely, an examination of the geographical distribution of research on immersive technologies in garment design reveals a pronounced concentration in China, which spearheads academic production, followed by countries in Asia and Europe. In this context, the studies by Hong et al. [22] and Hong et al. [20], which originated in China, are of particular

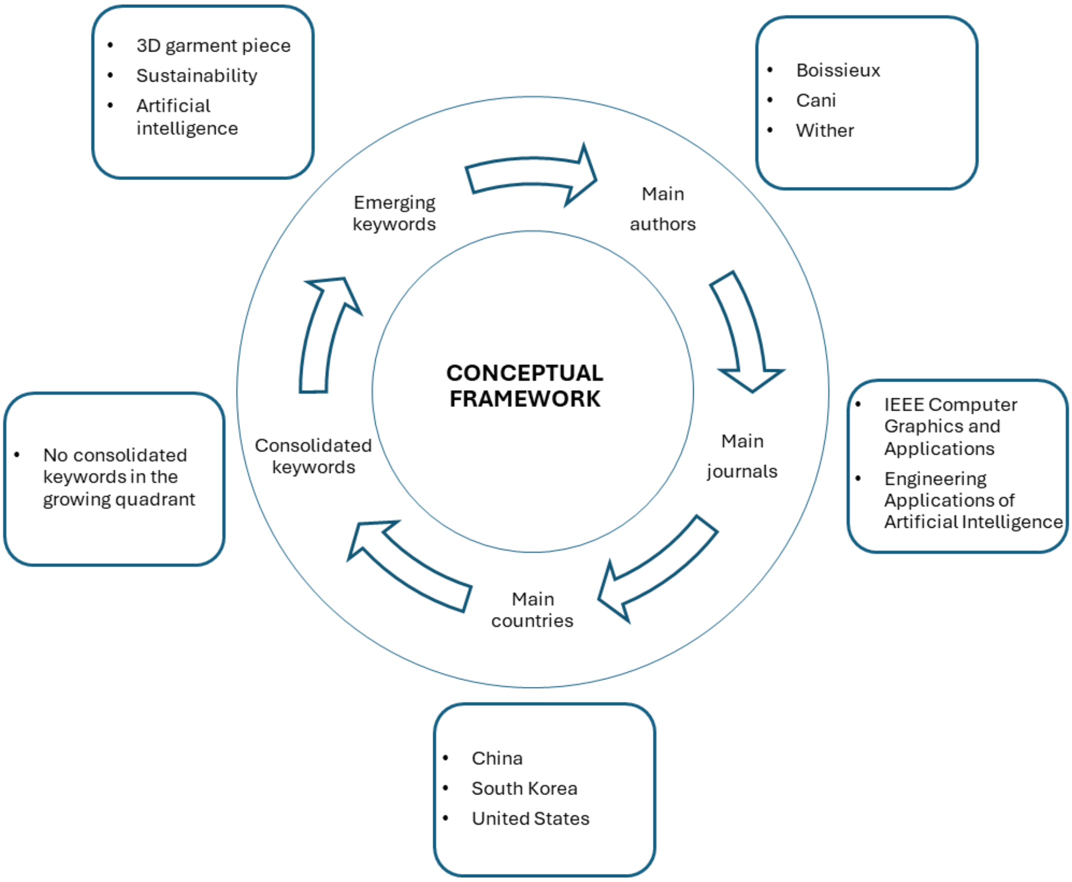

Figure 7. Framework of the scientific body.

significance. The first study presents a collaborative approach to the design of bespoke garments for individuals with severe scoliosis, utilising a virtual sensory evaluation procedure to enhance the 3D design of garments for atypical morphologies. The second study proposes a design process based on 3D to 2D virtual simulation, validating the efficacy and customisation of the design. Both studies emphasise China's leadership in the integration of immersive technologies, providing advanced and customised solutions with an emphasis on interactivity and inclusion.

The examination of keywords reveals the emergence of novel trends in the domain of garment design, as facilitated by immersive technologies. The quadrant of emerging terms includes concepts such as 3D garment pieces, sustainability, artificial intelligence, digital fashion and design collaboration, which are identified as having high growth potential. In their 2024 study on digital fashion, Lin, Li and Xia examine how virtual clothing design elements, such as novelty and sociability, affect the purchase intention of Chinese consumers. This highlights the relevance of digital fashion and its link to consumer motivations. Liu and Cheng [26] examine the role of artificial intelligence in fashion design, emphasising the integration of AI and virtual reality to anticipate trends and enhance design precision. They elucidate the influence of AI on the industry. The two studies demonstrate the progression towards enhanced interactivity and personalisation in the domain of garment design.

Figure 7 presents a consolidated framework that synthesises and summarises the research results. This visual representation synthesises the key findings, offering a structured view of the main trends and relationships identified, facilitating comprehension of the most relevant elements of the study.

Comparison with other studies

The geographical distribution of academic production on immersive technologies in apparel design is consistent with the findings of Goel et al. [27], who also identify China as the leading nation in terms of publications, followed by the United States and France. Both studies emphasise China's pre-eminence in this field, indicating a pronounced focus on Asia for research on immersive technologies applied to fashion design. However, the current research provides greater detail by pointing out countries with lower participation, such as Portugal and Italy, which was not explicitly mentioned in the aforementioned study. Moreover, Puspitasari et al. [28] also identify the prominence of Asia and Europe, but concentrate on the evolution of virtual reality in fashion fairs, a more specific area of focus than the one addressed in the current study.

Table 2. Research gaps.

Category	Gap	Research Question
Technological integration	Lack of synergy between VR/AR and AI	How can the integration of VR, AR and AI optimize design processes, customization and consumer interaction in the fashion industry?
Sustainability	Little explored environmental impact	How can immersive technologies, such as VR and AR, contribute to more sustainable fashion design and reduce its ecological footprint in production and distribution?
Accessibility	Barriers for SMEs and emerging designers	What strategies can overcome economic, technological and training barriers in the adoption of immersive technologies in small fashion companies?
Consumer Experience	Limited interaction between consumer and technology	How do immersive technologies, such as AR and VR, affect brand perception and the purchasing decision process in fashion consumers?
Product customization	Limited real-time customization	How can synergies between VR, AR and AI facilitate real-time customization of clothing based on consumer preferences?
Ethics and sustainability	Insufficiently researched social and ethical implications	What are the social and ethical implications of the mass adoption of immersive technologies in fashion design and its impact on culture and employment?
Usability	Lack of studies on user experience in VR/AR	How can you improve user experience on virtual design platforms and what impact does this have on consumer satisfaction and loyalty?
Technology adoption	Limited research on technological barriers in small businesses	What are the technological and economic challenges faced by small businesses in adopting immersive technologies in fashion design?
Implementation in industry	Implementation in the production chain	How can immersive technologies, such as VR and AR, be integrated into the fashion production chain to improve efficiency and reduce waste?
Innovation in materials	Limitation in the integration of new technologies with innovative materials	How can immersive technologies like AR help in the development of new sustainable materials for fashion?
Collaboration between designers	Lack of collaboration between designers in virtual environments	How can collaboration between designers, using virtual environments and AR, enrich the process of collaborative fashion design and creation?
Manufacturing processes	Implementing VR/AR in manufacturing	How does the implementation of immersive technologies impact garment manufacturing processes, from design to production?
Market research	Lack of data on consumer acceptance	What factors influence consumers' acceptance of immersive technologies in the fashion sector and how do they affect their purchasing behavior?
Efficiency in design	Efficiency in garment design with VR/AR	How can immersive technologies such as VR and AR increase efficiency in the fashion design process, reducing time and costs?
Interaction in stores	VR/AR integration in physical stores	How can augmented reality and virtual reality be integrated into physical stores to improve the shopping experience and increase customer satisfaction?
Education and training	Need for training in immersive technologies	How can fashion designers be better trained in using immersive technologies such as VR and AR to enhance creativity and productivity?

In terms of keywords, the bibliometric findings of this study diverge from those of Goel et al. [27] who have identified terms such as "virtual reality" and "augmented reality" as being particularly prevalent. However, this study indicates that concepts such as "artificial intelligence" and "digital fashion" are becoming increasingly prevalent, while other established terms, such as "computer-aided design," are losing relevance. This trend is not explicitly referenced in studies such as Pawitan et al. [29], which focuses on the advances of virtual reality in the fashion industry specifically.

Ultimately, while the study by Sajovic et al. [30] concentrates on smart textiles, a comparable interdisciplinary approach and accelerated growth of research in fashion-related technologies is also evident. This serves to reinforce the relevance and dynamism of the field, albeit with a different focus on materials technologies as opposed to immersive technologies.

Research gaps

Table 2 delineates the principal research deficiencies in the domain of immersive technologies deployed in the context of clothing design. These gaps encompass a range of areas, from the integration of VR, AR and AI, to issues of sustainability, accessibility and consumer interaction with these technologies. They reflect key aspects that require attention to advance knowledge and facilitate the effective implementation of these innovations in the fashion industry.

Research agenda

The study of the applications of immersive technologies in apparel design is establishing itself as an innovative field that combines current technological trends with the needs of the fashion industry. It is recommended that this research agenda focus on areas that present both high development potential and gaps that still require attention in order to drive the adoption and evolution of these technologies.

One of the most promising areas of research is the application of 3D technologies in the creation of garments, including the development of 3D garment pieces and the enhancement of visualisation and functionality. It is imperative that research addresses the integration of these technologies into efficient design processes, with a particular focus on the creation of personalised garments and the optimisation of the consumer experience through virtual try-ons. Similarly, research should investigate how cost reduction in prototyping and production can contribute to a more agile and economical creative process.

The concept of sustainability is also gaining prominence. The incorporation of immersive technologies, such as virtual simulations and the utilisation of digitally enhanced materials, presents the possibility of reducing waste in the design and production phases. Nevertheless, there is a dearth of comprehensive studies examining the environmental and social implications of these techniques. Research should concentrate on how these technologies can optimise the use of sustainable materials in garment design, evaluating their feasibility and ecological consequences.

Furthermore, the development of AI in the realms of design customisation and fashion trend prediction represents a significant area of interest. Nevertheless, an examination of the extant literature reveals a dearth of studies investigating the integration of AI with immersive technologies, such as AR and VR. It is imperative that research addresses the manner in which these systems can be integrated to enhance the real-time customisation of garments and consumer interaction, which has the potential to transform both the design processes and the shopping experience.

Moreover, digital fashion has demonstrated considerable growth, particularly within virtual environments and the utilisation of digital garments on platforms such as video games and social media. This phenomenon necessitates research into the ways in which immersive technologies can facilitate the coexistence of digital fashion with traditional fashion, as well as how they could expand the possibilities of interaction between consumers and brands. The investigation of methods by which AR and VR can enhance the user experience in both virtual and physical environments represents a field of considerable interest.

Finally, it is imperative that further exploration be conducted into the essential aspect of collaboration in design. The utilisation of immersive technologies, such as 3D collaborative platforms, has the potential to transform the interaction between designers, engineers and consumers, thereby enabling the emergence of novel forms of real-time co-creation. Nevertheless, there is a paucity of research examining the ramifications of such collaborations and how they can facilitate innovation and creativity in the fashion industry.

In terms of gaps in the literature, several significant gaps have been identified. Despite the growing prevalence of virtual and augmented reality in fashion design, there is a paucity of research examining their integration with technologies such as artificial intelligence and machine learning. This limitation impedes the development of synergies that could optimise personalisation and consumer interaction. Moreover, while some studies have addressed the impact of digital technologies on sustainability, the current literature does not adequately address the environmental and social implications of their large-scale implementation.

Another significant gap in the literature concerns the accessibility of these technologies for designers and smaller-scale companies. The majority of studies have focused on large brands, thereby neglecting the economic, technological and educational barriers faced by emerging designers and small businesses in adopting these innovations. Furthermore, consumer interaction with immersive technologies has not yet been explored in depth, especially with regard to the influence on brand perception and purchasing decisions.

Implications

From a theoretical standpoint, the findings of this study contribute to the advancement of theories in the field of fashion design and immersive technologies, thereby broadening the understanding of the interaction between digital design and immersive tools. This approach integrates virtual reality, augmented reality and artificial intelligence, thereby facilitating the exploration of hitherto uncharted dimensions of creative processes, garment customisation and design collaboration. Furthermore, the research highlights deficiencies in the existing literature with regard to the sustainability and ethical implications of these technologies, underscoring the necessity for the development of theoretical frameworks that assess their environmental and social impacts.

From a political standpoint, the research underscores the necessity for the formulation of public policies that encourage the responsible and accessible utilisation of immersive technologies in the field of fashion. It is recommended that governments implement tax incentives or subsidies for small and medium-sized enterprises, which face significant economic and technological barriers. Furthermore, the study suggests the implementation of regulations that promote the utilisation of virtual prototypes as a means of reducing waste within the industry. Additionally, it proposes the establishment of regulatory frameworks that provide guidance on the ethical use of artificial intelligence and the customisation of products in virtual environments, with the objective of ensuring the protection of data and consumer rights.

In terms of practical implications, the results have direct implications for the work processes of designers and fashion companies. The incorporation of immersive technologies, such as virtual prototyping and fit testing in immersive environments, will facilitate a reduction in the time required for the creation process, a decrease in costs, and an enhancement of the consumer experience through real-time customisation. This approach will prove advantageous to both established brands and emerging designers and small companies, who will be able to gain access to previously inaccessible technologies.

Limitations

A significant limitation of this study is the methodological approach, which concentrated on a literature review and qualitative analysis. This may have resulted in the exclusion of more comprehensive or representative empirical studies of the industry. Moreover, the interpretation of the results may be subject to bias due to the lack of data on the actual adoption of immersive technologies in companies of varying sizes, particularly in small and medium-sized enterprises. It is important to consider these limitations when attempting to generalise the findings, as the research did not cover all contexts or practical applications of immersive technologies.

CONCLUSIONS

The study on the applications of immersive technologies in apparel design demonstrates the emergence of a new and promising field that combines technological innovation with creativity in fashion. The increase in research in this field reflects the growing academic and industrial interest in exploring the intersection between these technologies and textile design, thereby opening up new opportunities for customisation and sustainability in the industry. Nevertheless, significant shortcomings persist, particularly with regard to the integration of technologies such as artificial intelligence and machine learning, which have the potential to enhance design and customisation processes. Furthermore, there is a need for a more in-depth examination of the environmental and social impact of sustainability in fashion design.

The accessibility of these technologies for designers and small businesses also represents a challenge, necessitating an inclusive approach in future research. From a theoretical perspective, this study broadens the perspectives on digital design, proposing a more fluid integration of virtual reality, augmented reality and artificial intelligence. Government support is also crucial to promote the responsible and accessible use of these technologies, encouraging sustainability and ethics in their implementation. This field has significant potential to transform the fashion industry, with implications for both practice and theory.

Acknowledgement: *This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.*

Data Availability Statement: *The data may be provided free of charge to interested readers by requesting the correspondence author's email.*

Conflict of interest: *The authors declare no conflict of interest.*

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KERSEN LEAF EXTRACT (*Muntingia Calabura L.*) FOR YARN DYEING APPLICATIONS IN LOMBOK-INDONESIAN WEAVING ARTISANS

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ABSTRACT

This study aims to analyze the process of making natural dye extracts from Kersen leaves (Muntingia calabura L.) and the results of dyeing weaving yarn in weaving artisans in Lombok, Indonesia. This natural dye is expected to be an environmentally friendly alternative dye that uniquely enriches local cultural heritage. The cloth that has been dyed with kersen leaf extract is then fixed with three types of fixators, namely: alum solution ($Al_2(SO_4)_3K_2SO_424H_2O$), lime solution ($Ca(OH)_2$), and ferrous sulfate solution ($FeSO_4 \cdot 7H_2O$). The results of the study showed: 1) The technique of making natural dye extracts from kersen leaves carried out by the researcher through the extraction technique of materials with a composition of 200 grams of kersen leaves: 1,000 ml of water into 500 mL of extract solution while what the weavers did was 15 kg of kersen leaves: 30 litres of water into 15 litres of material solution that is ready to be used to dye woven yarn; 2) The use of fixators in addition to directing colors also locks the color on the dyed yarn so that it does not fade easily; the alum solution fixator produces brighter colors; the lime solution fixator produces colors that tend to brown; and the ferrous sulfate ban produces a darker color towards black. This finding recommends the use of kersen leaf extract as an alternative solution for environmentally friendly natural dyes to be used in yarn dyeing in the weaving industry.

KEYWORDS

Experimentation; Kersen Leaf Extract; Yarn Dyeing; Natural Dyes; Lombok Weaving.

INTRODUCTION

One of the most polluting industries in the world is the textile business [1]. The textile industry is one of the sectors that significantly contributes to Indonesia's economy. As one of the country's most important manufacturing sectors, the textile and clothing industry contributed 4.5% of overall foreign exchange exports, with a US $11.6 billion value for Indonesia in 2023 [2].

Behind its large contribution, one problem that threatens the environment arises: the emergence of a large amount of liquid waste from the batik industry process [3]. Dyeing textiles with azo dyes causes wastewater impacts that cause environmental pollution [4]. This increase in textile production and consumption is sometimes not balanced by its focus on optimal waste management [5], [6]. In particular, it is considered important for various relevant stakeholders to appropriately formulate waste management policies to overcome the impact of the textile and sewing industry processes and products as the second most harmful industry to the environment [7].

Dyeing and dyeing textile materials such as yarn in textile production, especially weaving in weavers, often use synthetic dyes. This is done because the type of synthetic dye is seen as more practical, economical, and easy to obtain. However, it seems that it has not been realized that the continuous use of synthetic colors will threaten the environment with toxic waste in the water and soil ecosystem and threaten human health. We know that the use of synthetic dyes in the textile production process, in addition to impacting environmental pollution, also threatens human health [8]. For this reason, it is necessary to find the right solution, which is very important. One of them is using natural dyes from the abundant natural resources of plants around the weavers.

The Kersen plant (*Mutingia calabura L.*) is an antioxidant and antibacterial neotropical tree widespread in Indonesia [9]. As a bioactive compound of the ethyl acetate fraction, Kersen leaf extract contains phenolic components. It has strong

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Received October 20, 2024; accepted March 13, 2025

antioxidant activity [10]. Pharmacologically, the benefits of kersen leaves are known to be a source of bioactive compounds for antidiabetic treatment [11]–[14], anti-inflammatory [15]–[17], antimicrobial [18], anti-acne [19], and antidepressants [20].

In the food industry, such as food, the use of kersen leaves (*Muntingia calabura L.*) as one of the potential sources of nutritional supplements with good antioxidant and anti-inflammatory qualities needs to be promoted for consumption to improve public health [21]. Meanwhile, in the beverage industry, it is also known that kersen leaves can be used for the manufacture of kombucha (a supplement drink from the fermentation process of tea leaves by the symbiotic culture of acid bacteria and yeast), which is safe for daily use [22].

Using kersen leaves in the eco-fashion textile industry has been tried for fabric dyeing materials with the eco print technique through a steaming process using iron, alum, and calcium carbonate fixation. The test results show that the highest level of color brightness appears when using alum fixation agents, while the darkest colors have been produced by iron fixation [23].

Based on several studies described above, previous researchers have conducted studies on kersen leaves according to their scientific fields. Kersen leaves are known to be used as ingredients in traditional medicines but can also be used for food, especially as food and beverage supplements. Kersen leaves in the food sector in the form of eco-fashion to dye fabrics with eco-print techniques that are considered environmentally friendly. However, the author has not found any research that examines the benefits of kersen leaves as a natural dye for woven yarn dyes. To fill the gap, researchers have observed the woven yarn carried out by weaving artisans located in Pringgasela Village, Pringgasela District, East Lombok Regency, Lombok.

The formulation of the research problems proposed in this manuscript is to: 1) Analyze the process of making dye extract materials from natural materials of Kersen leaves (*Muntingia calabura L.*) for the dyeing process of woven yarn through laboratory testing and empirical observations on weaving artisans; 2) Analyze the results of dyeing weaving threads using Kersen leaf extract (*Muntingia calabura L.*) which is fixed with alum solution, lime solution, and ferrous sulfate solution through laboratory testing and empirical observations on weaving artisans. This research is expected to significantly contribute to advancing the weaving industry by using kersen leaves to reduce environmental pollution. The results of this research not only have the potential to provide environmentally friendly solutions for weavers in the weaving industry's production process but can also be a reference for the development of other natural dyes in the future.

Figure 1. Kersen leaves for natural dyes

MATERIALS AND METHODS

Materials

The materials used in this study consist of primary materials, namely natural Kersen leaves (*Muntingia calabura L.*) and cotton weaving yarn measuring about 20-40 Ne (Number English), and secondary materials, namely fixators that function to direct and lock colors.

The natural dye primer used is Kersen leaves (*Muntingia calabura L.*) in Aceh, called "seri," in Java, it is called "seri" or "talok." In the Lombok sasak language, it is called "singgapor." This neotropical type of plant is easy to grow in tropical areas, such as Indonesia. Kersen tree is an evergreen tree with a height of 3–12 meters, constantly evolving and bearing fruit throughout the year. This plant has several names in some countries, such as Jamaican cherry, Panama berry, Singapore cherry in English, and Dutch called Japanese kers [24].

This research also uses cotton yarn material for weaving with the number 20-40 Ne (Number English). This cotton yarn forms woven fabric sheets and describes weaving motifs using a cross technique between warp yarn and weft yarn. In addition to primary materials, the research also uses secondary materials, namely fixators, such as alum solution ($Al_2(SO_4)_3K_2SO_424H_2O$), lime solution ($Ca(OH)_2$), and ferrous sulfate solution ($FeSO_4.7H_2O$), used to determine and bind colors so that they do not fade quickly. In addition to primers and substrates, there are additives such as Turkey Red Oil (TRO) and soda ash (Na_2CO_3) to facilitate the absorption of color in yarn fibers or fabrics during the dyeing process.

Tools

In addition to primary, secondary, and additional materials, this experimental process also uses extraction processing equipment in the form of: 1) steinless steel (not from iron because they affect the extraction results); 2) a stove for boiling kersen leaves; 3) a stopwatch to measure the boiling time of natural dyes; 4) a wooden stirring device; 5) a machete/knife/chopping device to reduce the particles of natural color raw materials so that they form small pieces or chips; 6) Digital PH meter paper, to measure the acidity or alkalinity level of a solvent (natural dyes must be in an acidic/alkaline atmosphere); 7) measuring or liter, in the form of a dipper of a certain size that functions to pour the extract into a bucket where the staining is placed; 8) a sieve, in the form of gauze of a certain size to filter the results of the decoction of kersen leaf extract; 9) fixation equipment in the form of a plastic bucket with a diameter of 40 cm; 10) thermometer to measure the temperature of water at the time of boiling; 11) jars, a place to store kersen leaf color extract before using for yarn dyeing.

Research location

The research location for processing kersen leaves as a natural dye in dyeing weaving yarn was conducted at the Sentosa Pringgasela Weaving Studio at Jalan Rinjani, RW. Sentosa Pringgasela Village, Pringgasela District, East Lombok Regency, West Nusa Tenggara Province and Instrument Chemistry Laboratory at the Universitas Pendidikan Indonesia.

Research methodology

This study used an experimental method to explore the natural color of Kersen leaf extract (*Muntingia calabura L.*). The research variables are the difference in fixators and in the dyeing process of cotton yarn as a weaving material. The natural dye of kersen leaf extract is a dependent variable while the fixator is in the form of alum ($Al_2(SO_4)_3K_2SO_4 \cdot 24H_2O$), lime solution ($Ca(OH)_2$), and ferrous sulfate solutions and solutions ($FeSO_4 \cdot 7H_2O$) as an independent variable.

Working procedure

The stages carried out in this study are: a) soaking cotton yarn using alum and soda ash TRO solution; b) processing of kersen leaves as natural dyes that are sliced into small pieces as needed; c) boiling of kersen leaves into an extract solution; d) the process of dyeing cotton yarn with kersen leaf extract solution 2 3 times; e) the process of fixing the color with alum, lime solution, and ferrous sulfate solution; and e) the process of drying and aerating the yarn by tying and hanging it until it is completely dry, not exposed to direct sunlight. Visually, the experimental stages of making kersen leaf extract for natural dyes of woven yarn are depicted in Figure 2.

Figure 2 shows research activities ranging from preparing and processing woven yarn, processing extract materials from kersen leaves, dyeing yarn, and color fixation. In detail, the working procedures in this study are:

Weaving yarn processing

The yarn is processed by wetting and cooking the woven yarn. The water used for wetting and cooking is healthy (groundwater), with a pH of 6.8.

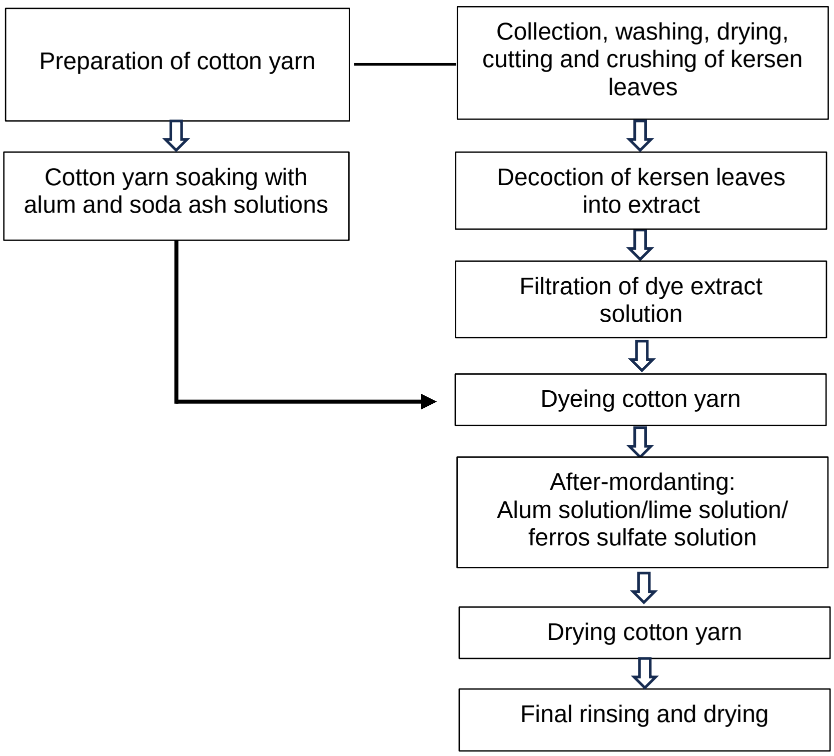


Figure 2. Stages of making dye extract and yarn dyeing process with kersen leaf extract dye.

The thread size used in this experiment is 40 (Ne). In this study, the cotton weaving yarn sample weighed 40 grams with a water volume of 1 L. Furthermore, 60 grams of alum and 13 grams of soda ash (Na_2CO_3) were put in the water. The yarn ripening process is carried out by boiling the yarn in water at a temperature of 95 ºC. The soaking and cooking of woven yarn aims to remove starch so that the absorption of natural dye yarn is optimal. The ratio of soaked yarn to water is 1 : 5 [25]. The cooked woven yarn is then drained to dry for the dyeing process.

Processing process of kersen leaf extract

Natural colors are processed from kersen leaves by extracting techniques by boiling the ingredients for a certain time. The ratio of kersen leaf ingredients, boiling water, and thread weight is: 2 kg 10 liters of water (1 : 5) [25]. The mass of the sample of kersen leaf extract in this study is 200 g with a volume of 1 liter of boiling water. To obtain data and treatment information in this study, kersen leaf extract was made based on the difference in time levels of 30, 45, and 60 minutes. At the same time, the extraction water's pH, the boiling's final temperature, and the extraction volume are also measured, as presented in Table 1 in the findings of the research results.

Yarn dyeing process

The yarn dyeing process was carried out 2 times in a solution of kersen leaf extract with a volume of 400 ml. The dyeing period is 10 minutes each; the dyeing process is repeated after the yarn is dry (not wrung out, not exposed to direct sunlight). The dyed yarn is prepared for the following process: fixing the color of kersen leaf extract on the yarn. The process data and dyeing results are presented in Table 2.

Final fixation process of weaving yarn

The final fixation process of weaving yarn uses the ingredients of alum solution, lime solution, and ferrous sulfate solution. The method of dipping the thread into the fixator solution is carried out once, with each dipping being 5 minutes long. The final fixated thread is then dried and rinsed with clean water. The fixation process directs and locks the color so it does not fade quickly. The three types of fixator materials were applied to three types of woven yarn samples that were classified based on the difference in the boiling time of the extract, namely 30, 45, and 60 minutes. Water pH levels, the length of dyeing time, and pH after the fixation process are also measured at this stage. The treatment results show the difference in yarn color results, as in Table 3 in the research results section.

UV-Vis and FTIR testing of color content from kersen leaf color extract

Testing of color extract samples from kersen leaves using UV-Vis (Ultraviolet-Visible Spectroscopy) spectrophotometry is done to measure light absorption in the ultraviolet spectrum and visible by substances present in water. This test is a spectroscopic analysis technique used to measure the absorbance or transmittance of a sample to light in the ultraviolet (UV, 200–400 nm) and visible (400–700 nm) wavelength ranges by substances present in water. This technique often identifies compounds, determines substance concentrations, and studies a material's optical or electronic characteristics.

FTIR (Fourier Transform Infrared Spectroscopy) is a spectroscopic analysis technique used to identify a compound's functional groups, molecular structure, and chemical interactions based on infrared light absorption. This technique measures how molecules absorb infrared light at a specific wavelength, producing a characteristic spectral pattern. The FTIR spectrum shows peaks specific to each type of chemical bond, allowing for in-depth analysis of the molecular structure and composition of the material.

RESULTS AND DISCUSSION

Research results

Woven yarn processing process

The process of processing woven yarn is carried out through wetting and cooking the woven yarn as described in the work procedure in the method section above to absorb the natural color of the extract from kersen leaves well absorbed by the yarn.

The proces and results of making natural dye extracts from kersen leaves

The process of making natural color extracts from kersen leaf materials carried out by weaving artisans has similarities with the process of making natural dye extracts carried out by batik artisans. However, there are slight differences that the author found through the process of observation and question and answer to the weavers, namely the formulation or comparison of raw materials with water used when making kersen leaf extract. In the context of this study, the ratio of raw materials and water used to boil ingredients is in line with the Indonesian National Work Competency Standards (SKKNI), with a ratio of 1:5 [25]. Meanwhile, the results of observations on weaving artisans obtained information are 1:2. In detail, the results of the process of making natural dye extracts are presented in Table 1.

Table 1 illustrates the comparison of the study sample, which includes sample mass, initial water volume, initial water pH, sample boiling time, water pH after boiling, final boiling temperature, and final volume after boiling. The difference in the length of boiling time from the data affects the pH level of the water after boiling and the final volume after boiling under relatively similar temperature level conditions. The results of the kersen leaf extract are visually presented in Figure 3.

Table 1. Data on the process and results of boiling kersen leaf extract.

No.	Sample Mass [g]	Initial Water Volume [ml]	Initial Water pH	Boiling Time [minutes]	pH of Water after Boiling	Boiling End Temperature [°C]	Final Water Volume after Boiling [ml]
1.	200	1 000	6.4	30	5.5	93	704
2.	200	1 000	6.4	45	5.6	93	650
3.	200	1 000	6.4	60	5.7	93	500

Figure 3. The color of the kersen leaf extract solution based on the length of boiling time.

Table 2. Process and results of fixation of woven yarn dyed with kersen leaf extract.

No.	Name of Fixation Material	Fixator Mass [g]	Initial Water Volume [l]	Initial Water pH	Fixation Dye Length [minutes]	pH Water before Fixation	pH Water after Fixation
1.	Alum	20	1	6.1	5	3.1	3.4
2.	Lime	20	1	6.1	5	14.0	14.0
3.	Ferrous sulfat	20	1	6.1	5	3.0	3.5

Results of dying and fixation woven yarn with kersen leaf extract

In practice, the process and results of dyeing woven yarn between laboratory results and data from the field are different. This condition concerns the pH level of water, kersen leaf material, the length of the extraction boiling process, and the composition of the fixation material. Color fixation on woven yarn uses alum, lime, and ferrous sulfate, lime, and ferrous sulfate solutions. Before the fixation process, the thread is dipped in the fixator solution, and the pH of the fixator solution water is measured. The same thing is also measured after the dyeing process. Based on the results of laboratory tests, information on process data and results of fixation of woven yarn was obtained, as shown in Table 2.

Table 2 informs the process and results of fixation of woven yarn dyed using natural dye extract of kersen leaves. Different pH levels are known. The final pH level of the fixator after use is generally greater (towards the normal direction). The dyeing and color fixation process results on woven yarn with kersen leaf extract show diverse results, as presented in Table 3.

Table 3 shows the data from laboratory research results related to dyed yarn samples associated with the type of fixation material used, boiling time, mass of fixation material, and dyeing time, as well as visualization of the resulting yarn color findings. The yarn dyeing process is done twice, with each sample being carried out for 10 minutes. After the dyeing process, the fixation process of woven yarn samples dyed with kersen leaf extract is carried out with a fixation time of 5 minutes. The data showed that the boiling time of kersen leaf extract affected the level of color intensity produced. The longer the boiling process, the stronger the intensity (dark color).

Table 4 shows the analysis of the yarn color fastness test against soap and sunlight washing from yarn samples boiled for 45 minutes, carried out by 7-cycle testing (as in Table 3). The yarn color fastness test analysis results against soap washing are known: yarn fixed with lime and alum has the highest average score of 4.5 (Good). Meanwhile, ferrous sulfate fixed yarns had a lower average value of 3-4 (Fairly Good). The results of the analysis of the results of the yarn color fastness test to sunlight are known: Calcium Carbonate fixated yarn has the highest average score of 5.0 (Very Good), ferrous sulfate fixed yarn is in second position with an average score of 4.5 (Good), and Aluminium Sulphate fixated yarn has the lowest average score of 4.0 (Good).

Table 3. Results of dyeing and fixation of woven yarn from kersen leaf extract.

No.	Sample name	Fixation Materials	Length of Boiling Extract	Fixation Materials	Yarn dyeing time	Yarn Color Results
1.	Kersen leaf extract 1	*Aluminium Sulphate*	30 minutes	50 gr	10 minutes	
			45 minutes	50 gr	10 minutes	
			60 minutes	50 gr	10 minutes	
2.	Kersen leaf extract 2	*Calcium Carbonate*	30 minutes	50 gr	10 minutes	
			45 minutes	50 gr	10 minutes	
			60 minutes	50 gr	10 minutes	
3.	Kersen leaf extract 3	*Ferrous sulfate*	30 minutes	50 gr	10 minutes	
			45 minutes	50 gr	10 minutes	
			60 minutes	50 gr	10 minutes	

Table 4. Color fastness test values with soap and sunlight washing.

Fixation Materials	Test no.	Yarn Color Fastness Test Value Against Soap Washing (Grey Scale)	Test Value of Yarn Color Fastness to Sunlight (Grey Scale)
Aluminium Sulphate	1	4-5 (Good)	4 (Good)
	2	4-5 (Good)	4 (Good)
	3	4-5 (Good)	4 (Good)
	4	4-5 (Good)	4 (Good)
	5	4-5 (Good)	4 (Good)
	6	4-5 (Good)	4 (Good)
	7	4-5 (Good)	4 (Good)
Calcium Carbonate	1	4-5 (Good)	5 (Very Good)
	2	4-5 (Good)	5 (Very Good)
	3	4-5 (Good)	5 (Very Good)
	4	4-5 (Good)	5 (Very Good)
	5	4-5 (Good)	5 (Very Good)
	6	4-5 (Good)	5 (Very Good)
	7	4-5 (Good)	5 (Very Good)
Ferrous Sulphate	1	3-4 (Fairly Good)	4-5 (Good)
	2	3-4 (Fairly Good)	4-5 (Good)
	3	3-4 (Fairly Good)	4-5 (Good)
	4	3-4 (Fairly Good)	4-5 (Good)
	5	3-4 (Fairly Good)	4-5 (Good)
	6	3-4 (Fairly Good)	4-5 (Good)
	7	3-4 (Fairly Good)	4-5 (Good)

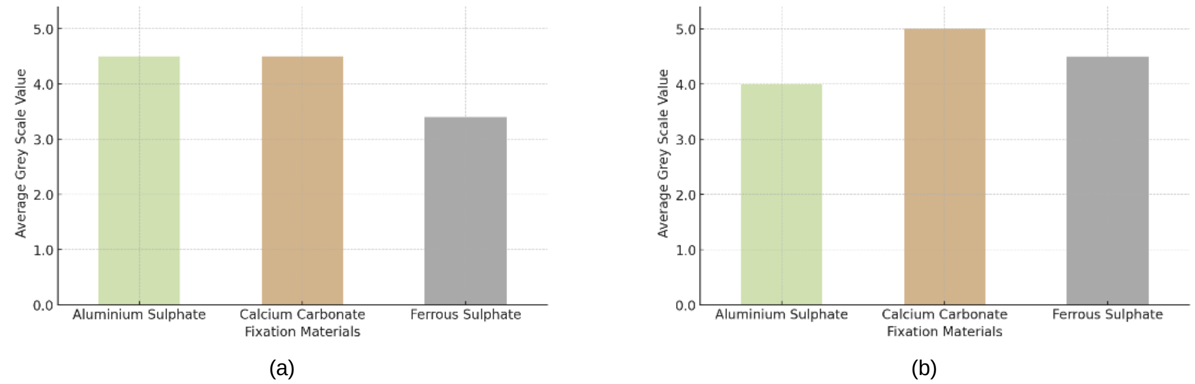


Figure 4. Average yarn color fastness to (a) soap washing, (b) sunlight test value.

Table 5. Results of dyeing kersen leaf color extract on woven yarn.

Yarn Before Dyeing Process	**Thread after dyeing by using a fixator**		
	Alum Solution ($Al_2(SO_4)_3K_2SO_424H_2O$)	**Lime Solution** ($Ca(OH)$	**Larutan Ferrous sulfate** ($FeSO_47H_2O$)
			

Visually, Figure 4 and Figure show the yarn color fastness test results to soap and sunlight washing. As a result of washing with soap, samples of yarn fixed with Aluminum Sulfate and Calcium Carbonate had the same result of 4.5, better than yarn fixed with ferrous sulfate. The results of the color fastness test of the yarn against the sunlight exposure resistance of calcium carbonate were fixed at a value of 5, which is the most resistant to sun exposure than the other two samples fixed with ferrous sulfate and aluminum sulfate.

As material for comparison with the data carried out by the researcher, as presented in Table 3 above and in Table 4, the data from field research from weaving artisans in Lombok is presented. The cotton yarn dyeing process for the weaving production process in this study uses natural dyes from kersen leaf extract (Muntingia calabura L.). The yarn dyeing process last 30 minutes to several hours while stirring evenly. To obtain optimal color dyeing results, 3 dyeing processes are carried out.

In the yarn dyeing process, several things must be considered: a) Make sure the yarn has been mordan and TRO; b) Make sure the solution is cool; c) Make sure the thread is evenly dyed in the solution; d) Dry the thread before re-dipping it into the solution; e) The thread should not be squeezed; f) The yarn should not be dried in direct sunlight; and g) The thread is simply aired until the liquid does not drip. The weaving yarn dyeing process can be seen in (see Table 1).

Table 1 above visualizes an example of the results of dyeing woven yarn from natural dyes of kersen leaf extract (*Muntingia calabura* L.) with different fixator materials. Dyeing with an alum solution fixator produces a bright original color; using a lime solution fixator tends to make a color in the direction of brown; and a ferrous sulfate solution fixator produces a color that tends to be blackish-gray. The findings are reinforced by field data related to the practice of dyeing cotton yarn for weaving production that has been carried out by weaving artisans at the research site, as presented in Figure 4 below.

Figure 5 visually shows the yarn dyeing process carried out by weavers in Pringgasela

Figure 5. Activities of weaving craftsmen in the process of dyeing weaving yarn.

Figure 6. Example of Sundawa motif woven fabric dyed with natural ingredients of kersen leaf extract.

Village, Pringgasela District, East Lombok Regency, West Nusa Tengga Province. The two images on the left show dyeing woven yarn using natural ingredients from kersen leaf extract, which is modified with an alum solution to produce a yellowish color. Meanwhile, the two images on the right show dyeing the yarn with kersen leaf extract material fixed with a lime solution, creating a color that tends to brown.

The image on the left of Figure 6 shows the yarn dyed using kersen leaf extract (*Muntingia calabura L.*). Furthermore, by the weaving craftsmen, the yarns that have been dyed through the dyeing process are used to make woven fabrics through the process of crossing the warp yarn and the weft yarn so that it forms the desired motif as shown in the picture on the right.

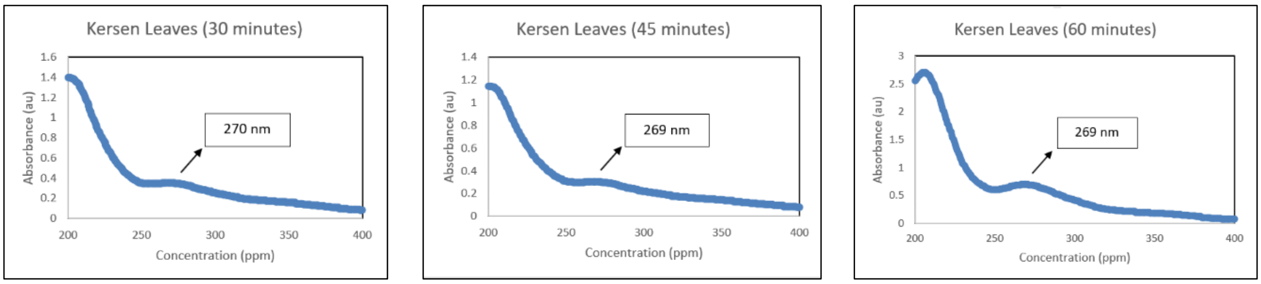
The woven yarn dyed with the natural dye extract of kersen leaves, as described above, is then used by weavers in the weaving production process. The following is an example of a visualization of woven products with Sundawa weaving motifs that use yarn from the dyeing process of kersen leaf extract with different fixators as one of the Sasak weaving motifs in Peringgasela Village, East Lombok Regency, West Nusa Tenggara Province.

UV Vis and FTIR test results

Based on the results of the analysis of the UV-Vis test on the natural dye extract solution of kersen leaves, it is known that the maximum wavelength produced from the three treatment data of kersen leaves with different boiling time durations is 30, 45, and 60 minutes

Figure 7 illustrates the UV absorption data showing that kersen leaf extract was detected at absorption at a maximum wavelength of 270 nm for kersen leaf extract in samples with a boiling time of 30 minutes (Figure 7(a)) and 269 nm for kersen leaf extract at temperatures of 45 (Figure 7(b)) and 60 minutes (Figure 7(c)). The uptake produced from these three data is included in plants' absorption range of flavonoid compounds.

Based on literature searches, flavonoid compounds contained in plants have a maximum wavelength in the range of 200-400 nm [26]. Kersen leaves contain flavonoid compounds, which are medicinal compounds that can be used as antioxidants, antibacterial, and anti-inflammatory. The higher the concentration of kersen leaf extract inhibiting bacteria is in the extract, the higher the concentration of 96% with a methanol solvent [27].



(a) (b) (c)

Figure 7. The maximum wavelength of kersen leaves from boiling the extract was: (a) 30, (b) 45, and (c) 60 minutes.

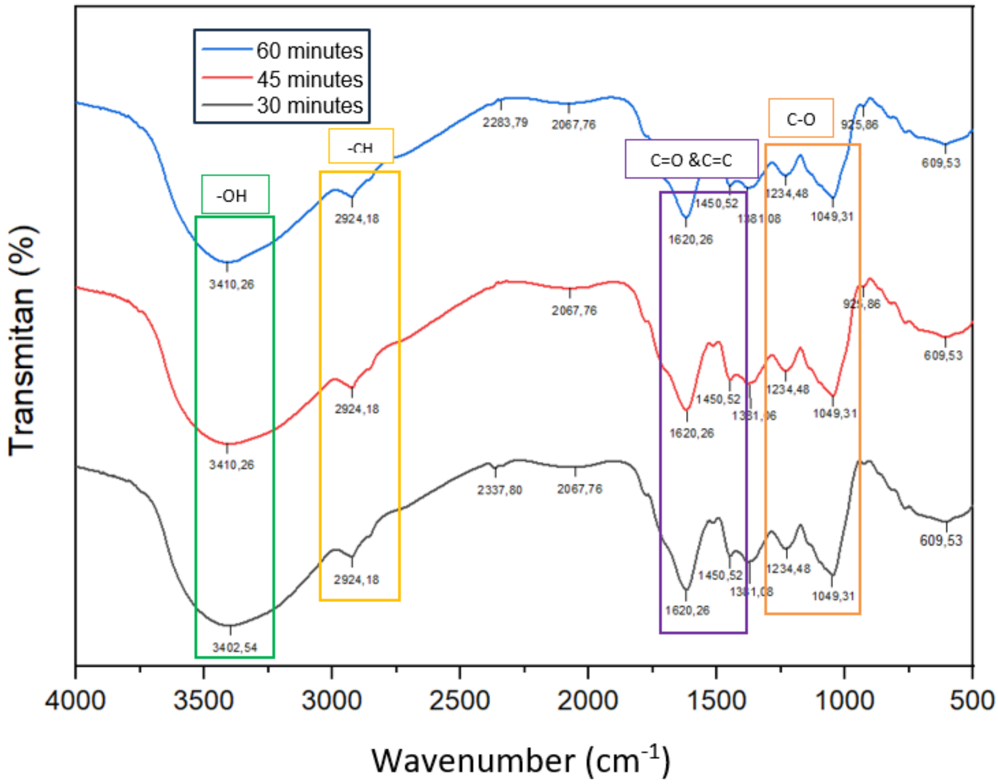


Figure 8. The FTIR spectrum of kersen leaf extract is different based on the boiling time.

The FTIR spectral analysis in Figure 8 above obtained several peaks in various absorption regions, indicating the presence of flavonoids in kersen leaf extract with main/distinctive peaks of (-OH), -CH, C=O, C-O, and C=C aromatic. Spectra analysis showed that there was a wide peak in the absorption area of almost the same wave number for kersen leaf extract in 30-minute, 45-minute, and 60-minute boiling samples, respectively, namely 3402.54 cm^{-1}, 3410.26 cm^{-1}, and 3410.26 cm^{-1}, which were the absorption of -OH *stretching* for the hydroxyl functional group. There is a sharp peak in the absorption area of the same wave number, 2924.18 cm^{-1} in all three spectra. The peak is the absorption of -CH alkyl (-CH sp3). In addition, aromatic C=O and C=C functional groups can be indicated by absorption at the same wave number of 1620.26 cm^{-1} and 1450.52 cm^{-1} in each spectrum at different temperatures. There is a peak at wave number absorption of 1234.48 cm^{-1}, indicating the presence of a C-OH group, and a peak at wave number absorption of 1049.31 cm^{-1}, indicating the presence of C-O-C, including aromatic C-O and aliphatic C-O.

Discussion

The process of making natural dye extracts from kersen leaves is carried out before the cotton yarn dyeing process. In the laboratory research process, researchers process yarn using alum auxiliaries and soda ash (Na_2CO_3) in water. While the yarn is processed by weaving, artisans also process the yarn by soaking cotton yarn using TRO. The purpose of this activity is to make the condition of the yarn clean from starch attached to the yarn so that at the time of dyeing, the color absorption process by the yarn is optimally successful.

The process of making kersen leaf extract that the author has carried out uses 200 g ingredients with a volume of 1 000 ml of boiling water. To determine the difference in the treatment, the researcher determined the boiling time of the kersen leaf color extract for 30, 45, and 60 minutes. After boiling, it is known that the final volume of water after boiling shows a difference (see Table 1). The extracted results are then stored in jars for the following process (Figure 3).

The dyeing yarn stages is carried out according to the need for quality and color intensity. In the context of the laboratory research that the author has conducted, the dyeing of woven yarn was carried out twice on the color extract with a ratio of 1 : 5, which was boiled with a time difference of 30, 45, and 60 minutes (see Table 1). The stages of the dyeing process start from the stage of preparing woven yarn materials in the form of cotton yarn before the dyeing process, the stages of processing kersen leaf materials as natural dyes, the stages of making extracts with a ratio of 1 : 2 (in this study: 15 kg of ingredients and 30 liters of water), continued to the dyeing stage of woven yarn 3 times the dyeing process for maximum results, and the mordanting or color fixation process using alum materials, lime, and ferrous sulfate to direct and bind the color of the yarn so that it does not fade easily (see Figure 2).

The results of dyeing the woven yarn using natural dyes of kersen leaves using alum, lime, and ferous sulfate fixator materials produce different colors. The data in Table 3 above shows the color of the dyeing results of woven yarn as follows: The result of dyeing the yarn with kersen leaf dye extract using an alum solution fixator ($Al_2(SO_4)_3K_2SO_424H_2O$) produces a light and natural color; in the example of the color above, it is more towards light yellow; Results of yarn dyeing with Kersen leaf dye extract using a lime solution fixator ($Ca(OH)_2$) produced a color that tended to lead to brownish, and the result of dyeing the yarn with kersen leaf dye extract using a fixator of ferrous sulfate solution ($FeSO_47H_2O$) produces a yarn color that tends to be darker, namely blackish ash. The same result is reinforced by the data presented in (Table 4 and Figure 4), which informs the dyeing practices carried out by weaving artisans in the yarn dyeing process through dyeing techniques using kersen leaf extract, which is modified with alum solution, lime solution, and ferrous sulfate solution. The same findings were obtained from applying the eco print technique through a steaming process with kersen leaf material. By using iron, alum, and calcium carbonate fixation it is known that the highest level of color brightness appears when using alum fixation agents.

In contrast, the darkest color has been produced by iron/ferrous sulfate fixation [23]. The color of the yarn produced from the laboratory dyeing process (Table 3) is generally similar to the color results carried out by weaving artisans empirically in the field where they produce woven yarn (Table 4 and Figure 4). The findings are reinforced by the results of observations and interviews conducted by the author on weavers, who emphasized that the intensity of the brightness level and color concentration produced from the natural dye material of kersen leaves is greatly influenced by several variables, including the amount of material compared to the water used; the length of time in the dyeing process; and the amount of yarn dyeing done. The more materials used and the longer the dyeing time, and the repetition of dyeing more than three times, the more intense and stronger the color will be. This is in line with research that shows the influence of temperature and dyeing time of cotton yarn [28]. The same findings were obtained from previous research, which stated that the pH level and type of mordant also affect the dyeing results of cotton batik fabrics [29][30].

The yarn color fastness test results against soap and sunlight washing in Table 4 above provide an overview of the quality of yarn color fastness based on the type of fixation used. Testing of three samples of yarn dyed in an extract solution that was boiled for 45 minutes and testing the color fastness of yarn to soap and sun washing as many as seven cycle showed consistent results. Based on these data, the results of the yarn color fastness test against soap washing in the samples of aluminum sulfate and calcium carbonate fixed yarns were better than those of staple fixed yarns (see Figure 4), while the results of the yarn color fastness test with modified iron sulfate were the most resistant to sun exposure compared to the other two samples (see Figure 6). Thus, it can be concluded that the results of the yarn color fastness test against soap washing recommend threads repaired by aluminum sulfate and calcium carbonate. In contrast, the yarn color fastness test results to sunlight recommend using calcium carbonate fixation.

The results of the UV-Vis test on three types of kersen leaf extract solutions, as visualized in Figure 7 above, generally did not find significant differences. In addition, the maximum wavelength absorption of the three data in Figure 6 does not provide a significant difference when looking at the difference in the variation in the length of the extract boiling that has been carried out. The uptake is close to other studies in identifying flavonoid compounds in kumak leaves with the maximum detected wavelengths of 271.2 nm and 272.2 nm [31]. Kersen leaves showed absorption at 269 nm and 259.5 nm wavelengths, which were suspected to be flavonoid compounds [32]. The findings are different from the length of the qualitative test with ethyl acetate extract of kersen leaves using quercetin parent solution, which was analyzed using a UV-Vis spectrophotometer with a maximum wavelength of 438 nm, forming a yellow color indicating that the sample contains flavonoids [33].

Based on the FTIR spectrum presented in Figure 8, the three spectra do not have significant differences; kersen leaves at boiling times of 30, 45, and 60 minutes do not provide much difference when viewed from the change in wavenumber shift in each FTIR spectrum. However, the length of the heating duration shows differences in intensity and peak shape, so heating affects the chemical composition or concentration of certain compounds in the extract. The findings suggest that this spectrum can be used to identify the main functional groups in the extract and how the heating process affects the presence or intensity of certain compounds. Kersen leaf extract has active compounds with functional groups suitable for dyeing batik fabrics that are environmentally friendly, durable, and aesthetically pleasing to be applied to the textile industry, especially batik.

The existence of weaving as a livelihood for weaving artisans needs to be supported by various related parties so that its existence continues to be sustainable. Weaving is one of the potentials that can be developed to grow the economic wheels of the community, which has traditional knowledge and cultural expressions of the nation that need to be protected so that they continue [34]. To support and help traditional weaving SMEs sustainably in terms of social, economic, and environmental performance, it is considered necessary to have a creative and social entrepreneurial orientation in protecting local resources and taking market resources to gain profits [35]. In addition, efforts to improve the quality of weaving processes and products need to be developed with a quality concept to formulate policies for developing this industry as a cultural product built on cultural and economic principles and the mission of weaving products [36]. Thus, traditional weaving is a major income source for weavers and marketers of Ghana's indigenous woven fabrics [37]. The same thing is also found in the role of women weavers in the Batak Toba tribe of North Sumatra in Indonesia; in addition to inheriting and maintaining Ulos weaving as a cultural identity of the community, it also provides an overview of social and economic conditions [38].

The problem of pollution in the dyeing process in the field of weaving in Lombok, Indonesia, has similarities with the dyeing process of materials for the production of mat crafts in the Mekong Delta of Vietnam, namely in the dyeing process of materials that produce waste as a source of environmental pollution [39]. Natural dyes derived from plants in the form of kersen leaves is used in the dyeing of woven yarn with aesthetic, cultural, economic, and environmental considerations. The aesthetic aspect is that the dyeing of woven yarn using kersen leaves produces a distinctive natural, soft, and authentic color on Lombok songket woven fabrics. Cultural aspect: the use of natural dyes of kersen leaves is part of local tradition and wisdom in maintaining cultural identity and traditional heritage in the manufacture of woven fabrics. Economic aspect: natural dyes for kersen leaves are available and easy to get around artisans so that they are not dependent on imported materials, and production costs are reduced. Environmental aspect: natural dyes of kersen leaves are environmentally friendly because they are free from harmful chemical elements and pollute the environment. Kersen leaves are also biodegradable materials, which are materials that are easily decomposed by nature so that they do not cause harmful waste that can pollute the soil or water.

Natural dyes used to process woven yarn for artisans are generally taken from parts of plants consisting of tubers, roots, stems, leaves, and fruit peels [40]. The use of natural colors in the yarn dyeing process has been identified; 13 plant species are used as dyes, and nine species as color binders used by traditional woven fabric artisans in the Pringgasela area, East Lombok, West Nusa Tenggara [41]. Natural dyes from plants are used in Sukarara village, Jonggat District, Central Lombok Regency, West Nusa Tenggara Province. The plant parts include bark, stems, leaves, fruits, seeds, and wood. Eight types of plants produce colors, including red (teak bark and leaves and betel leaves), black (mango leaves), purple (bark and Turi leaves), blue (Tarum leaves and Pace leaves), light green (Pace fruit), dark yellow (Face wood), brown (Acid seeds), and blackish brown (Mahogany bark) [42]. However, the use of natural dye extracts from kersen leaves has not been found. Therefore, natural colors from kersen leaves are expected to add to the richness of natural colors that are environmentally friendly; besides that, it is also believed to be an effort to prevent synthetic dyes that are quite dangerous and cause environmental pollution.

Based on the findings of the research on the use of kersen leaf extract, the author recommends that the government and weavers explore plants, especially kersen leaves, as an effort to take advantage of the potential of abundant natural resources and promote natural wealth in the surrounding area as an effort to strengthen local cultural identity. This is in line with the report of research results in the development of the textile industry, especially in the field of batik, through the process of exploring local plant diversity as a source of ideas to create motives in addition to lifting natural wealth from the environment as well as to strengthen the value of local cultural identity [43]. In addition, using natural dyes also has advantages, including being cheaper, environmentally friendly, and producing distinctive colors [44]. Thus, efforts to use natural colors for the dyeing process of woven yarn are an action for health and add value in terms of economy, empowerment, and intergenerational inheritance efforts [45].

CONCLUSION

The use of kersen leaves as a natural dye in the process of dyeing songket fabric weaving yarn for Lombok weaving artisans. This effort takes advantage of the potential of abundant natural resources in the form of flora around the artisan environment. In addition, using natural dyes for kersen leaves fosters awareness among artisans about reducing or abandoning chemical (synthetic) dyes and switching to natural dyes. Using natural dyes will sustainably create a green and environmentally friendly Lombok weaving industry, save production costs, and increase economic potential and independence.

The selection of natural materials such as kersen leaves to be used as natural color extracts and using fixation materials through the proper process can produce distinctive natural, soft, durable, and environmentally friendly colors. The results of the dyeing experiment of kersen leaf extract on woven yarn produced yarn color intensity with several shades and varying color levels, such as the original bright yellow, brown, and blackish gray. Findings about more varied woven yarn colors with a certain brightness level on types of yarns other than cotton with different fixator materials need further research. Based on the results of the study, it is recommended to use natural dyes such as kersen leaf materials through the extraction and fixation process to preserve the value of local wisdom and added value in Sasak Lombok weaving artisans and weaving artisans in different places.

Acknowledgement: *The author would like to express his gratitude to: 1) Mr. Maliki, Head of the Santosa Weaving Gallery, Pringgasela Lombok, for the assistance and information that have been provided by the author in the process of writing research related to the dyeing of Lombok woven yarn; 2) The weavers who have allowed being allowed being interviewed and observed; 3) Prof. Dr. Heli Siti Halimatul Munawaroh, M.Si. and Agnia Muftiasih, S.Si., Instrument Chemistry Laboratory of the Universitas Pendidikan Indonesia; and Supardi R. S Textile Manufacturing and Testing Laboratory, Textile Engineering Study Program, Faculty of Industrial Technology, Universitas Islam Indonesia which has helped to test in analyzing research data.*

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AIMS AND SCOPES

“Vlakna a Textil” is a peer-reviewed scientific journal serving the fields of fibers, textile structures and fiber-based products including research, production, processing, and applications.

The birth of this journal is connected with three institutions, Research Institute for Man-Made Fibers, Svit (VÚCHV), Research Institute of Chemistry of Textiles (VÚTCH) in Žilina and Department of Fibers and Textiles at the Faculty of Chemical Technology, Slovak Technical University in Bratislava, having a joint intention to provide, utilize and deposit results obtained through the research, development and production activities dealing with the aforementioned scopes. „Vlákna a Textil“ journal has been launched as a consequence of a joing of existing magazines „Chemické vládkna“ (VÚCHV) and „Textil a chémia“ (VÚTCH). Their tradition should provide a good framework for the new journal with the main aim to create a closer link between the basic element of the product - fibre and its fabric - textile.

Since its founding in 1994, the journal introduces new concepts, innovative technologies and better understanding of textile materials (physics and chemistry of fiber forming polymers), processes (technological, chemical and finishing), garment technology and its evaluation (analysis, testing and quality control) including non-traditional applications, such as technical textiles, composites, smart textiles or garment, and nano applications among others. The journal publishes original research papers and reviews. Original papers should present a significant advance in the understanding or application of materials and/or textile structures made of them.

VLÁKNA A TEXTIL
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