

Development and Evaluation of Bamboo–Wool Non-Woven Textiles for Fashion Accessories: Material Performance and Consumer Acceptance

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ABSTRACT

In this study, researchers investigated the production of new types of non-woven fabrics made from bamboo fibres, which are renewable biomass resources suitable for use in the development of fashion accessories. The study examined various aspects of bamboo fibre, including differences among three bamboo culm grades, and optimised bamboo-wool composite materials by performing both physical characterisation and assessing how consumers perceive these materials. To develop the bamboo composites, researchers used an experimental design methodology. They included the following methods in their experimentation process: Grading of Bamboo Culms into Grades A, B & C, Low-Impact Alkaline Fibre Extraction Methodology, Wet Felting Fabrication Process, Scanning Electron Microscopy (SEM) Analysis, and Tensile Strength Testing of Composites. Researchers also conducted an online survey to assess whether consumers accept or reject the sustainable aesthetics of bamboo-based fashion accessories. Results showed that Grade A Bamboo had the best characteristics for processing efficiency and fibre structure. In addition, SEM images show better uniformity of fibre distribution and increased bonding forces between bamboo fibres when bamboo fibres were blended with wool. Also, results indicate that the most durable fabric tested contained 50 per cent bamboo and 50 per cent wool and produced the best combination of softness and resistance to shrinkage. Cotton-lined versions of this fabric were found to be the most structurally stable. In addition, results indicate that 92.5% of consumers who responded to our survey indicated that they would recommend purchasing one of our developed products. Furthermore, multiple linear regression analysis is demonstrated to be effective at predicting consumer behaviour ($F(2,117) = 64.125$, $p < 0.001$), accounting for approximately 52.3% of the variability associated with purchase intentions. Aesthetic appeal emerged as the primary determinant ($\beta = 0.481$, $p < 0.001$), followed closely by sustainability perception ($\beta = 0.392$, $p < 0.001$). While a formal environmental life cycle assessment (LCA) was not conducted, meaning environmental performance was inferred from raw material selection and processing rather than directly quantified, the study concludes that bamboo–wool non-woven textiles offer a functional, visually appealing, and potentially low-impact alternative to conventional fashion accessory materials.

KEYWORDS: Bamboo fibre, Non-woven textile, Low-impact fashion accessories, Material characterisation, Consumer acceptance

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1. INTRODUCTION

The textile sector is among the largest in terms of water use, reliance on non-renewable resources, chemical-intensive processes, and the rising volume of textile waste (Niinimäki et al., 2020). The widespread use of synthetic fibres derived from fossil fuels has led to several environmental issues, including the production of non-biodegradable materials, greenhouse gas emissions, and landfill waste (Ghalachyan, 2018). In fact, the volume of textile waste has been growing year by year,

with a need for sustainable and renewable solutions in the textile production system (Kerr, 2017). Therefore, the sustainable development of materials is a key research focus in textiles, aiming to minimise the environmental impact of fabrics and promote actions aligned with the principles of the circular economy. Natural fibres have gained greater interest as an alternative to synthetic fibres because of their biodegradability, renewability and less environmental impact. Bamboo is one of the natural fibres that is a promising raw material for the sustainable fibre textile industry due to its high growth

rate, short harvesting period and desirable mechanical properties (Emamverdian et al., 2020). Bamboo can mature in 3–5 years, has a high strength-to-weight ratio, low density and good stiffness when compared to conventional natural fibres (Javadian et al., 2019). Moreover, bamboo fibres are bacteria-resistant, absorbent, UV-resistant, and breathable, which is ideal for textiles (Rocky & Thompson, 2018).

Despite these benefits, raw bamboo fibres possess a complex lignocellulosic matrix with a high lignin content, rendering the extracted fibres stiff, coarse, and structurally smooth (Chokshi et al., 2022). Characterised by wide cell walls and specific microfibrillar angles, these fibres are structurally comparable to natural glass fibres (Behera et al., 2024). Unlike wool, bamboo lacks surface scales, making 100% bamboo fibres inherently incapable of interlocking via traditional wet-felting techniques. This structural morphology creates unique challenges for standard textile processing, necessitating proper extraction and refinement techniques to remove non-cellulosic components, reduce stiffness, and enhance its flexibility and suitability for textile applications (Jalil, 2025). While the structural morphology of bamboo presents unique challenges for standard textile processing, mastering the initial extraction stages is critical. These processes directly influence the fibre's dispersion, alignment, and interfacial adhesion within the polymer matrix, ultimately determining the mechanical properties, strength, and overall performance of the resulting bio-composites (Kumar et al., 2019). The extractive process of bamboo fibres can be done using mechanical, chemical, or mechanical and chemical methods. While it limits chemical use and maintains the natural fibre structure, mechanical extraction is time-consuming and less efficient, yielding inconsistent fibre and damaged structure (Zhao et al., 2023). Chemical extraction yields finer fibres but may also raise environmental concerns due to the use of harsh chemicals (Hu et al., 2020). The synergistic effect of low-concentration alkaline treatment along with mechanical processing has been seen to improve fibre quality while reducing environmental impact in previous studies (Rocky & Thompson, 2018). Bamboo is a fast-growing, biodegradable, and high-strength biomass source, promising for sustainable textile applications. Low-impact extraction methods and non-woven fabrication processes enable a more circular textile production process and less reliance on petroleum-based synthetic fibres.

Moreover, the use of bamboo helps to reduce waste and encourages sustainable innovation of materials to support future textile production systems. To design eco-friendly textiles, designers should strategically choose between mechanical and chemical processes, considering their environmental impact and the functional needs of the garments (Hwui & Jalil, 2025).

The advantage of the mechanical process (crushing and retting) is reduced chemical use and reduced wastewater, but the final choice is complex due to sustainability benefits. Natural fibre strength and tactile/craft-based aesthetics are maintained with mechanical processing, which makes it suitable for artisanal production. Chemical processes, on the other hand, provide softness, uniformity, and scalability, which are essential for mass-market fashion and technical textiles (Jalil, 2022). This treatment increases the fibre's effective surface area, thereby promoting superior interfacial compatibility within textile matrices (Behera et al., 2024). In the end, any choice will depend on the final use, as the mechanical will favour ecological integrity, whilst the chemical will favour industrial performance. Sustainable manufacturing is one way of improving environmental performance in terms of sustainability.

Experiencing significant growth, the nonwoven sector now accounts for about a third of the overall textile market, supplying materials for both short-term disposable items and long-lasting products (Debnath, 2017). Nonwoven sector: Fabrication of non-woven textiles using the felting technique has emerged as a sustainable textile production method, due to reduced use of synthetic binders and fewer production processes. Unlike conventional textile manufacturing, wet felting is a process where cohesive textile structures are formed without any weaving or knitting process by entangling natural fibres through the action of heat, moisture, pressure and mechanical agitation (Aktaş & Mäkelä, 2019). As these localised environmental conditions cause the protein fibre shafts to absorb moisture and swell, their surface scales lock together permanently. Furthermore, the deliberate retention of structural air gaps within the material matrix further enhances its unique properties, ultimately yielding a unified and stable textile surface (Almalki & Tawfiq, 2023).

Some of the previous studies have shown that wool-based non-woven systems contribute to enhancing the recyclability and the reduction of textile wastes (Almalki & Tawfiq, 2023). Very few studies have focused on incorporating bamboo fibres into a non-woven felting system and have examined the structural performance, dimensional stability, and mechanical properties of bamboo fibres for sustainable textile applications. To utilise bamboo in nonwoven architectures without relying on synthetic chemical binders, it must undergo a low-impact refinement process and be strategically blended with a scalable matrix such as wool (Aktaş & Mäkelä, 2019; Jalil, 2025). Prior research has focused heavily on chemical extraction (viscose/rayon processing), which yields ultra-soft fibres but causes severe environmental toxicity (Hu et al., 2020), and on pure wool nonwovens for industrial insulation or basic apparel (Almalki & Tawfiq, 2023). However, a critical research gap remains: the systemic relationship between raw bamboo culm

grading, eco-friendly mechanical-alkaline extraction, and the resulting mechanical performance of hand-felted bamboo-wool non-wovens has not yet been established. Apart from its environmental benefits, bamboo is also used in the traditional crafts of Sarawak, Malaysia, and has been a significant raw material in the production of handmade products and native crafts. The introduction of bamboo into modern textile materials could help maintain traditional material knowledge and foster sustainable material innovation.

Although bamboo fibre fabrics have gained considerable popularity, little research has been conducted systematically to explore relationships between the grading of bamboo culms, eco-friendly extraction technologies, non-woven felting fabrication process, and performance properties of the textile for sustainable textile applications. To address the gap in current literature, this study develops an innovative framework that merges indigenous material knowledge with conventional structural engineering. Bamboo is embedded in the tradition of Sarawak's craft communities as a crucial resource for producing both structurally and functionally made items. The study integrates Sarawak's traditional practice of low-energy/artisanal material manipulation into a standardised, hand-manipulated wet felting fabric production technique. The focus on developing a set of fashion accessories (i.e., bags, pouches, headbands) will provide a targeted response to the limited structural capabilities of natural non-wovens. In contrast to garments, which must exhibit flexible drapability and high elasticity, fashion accessories must demonstrate high dimensional stability when subject to loads; they must also possess unique directional tensile strengths and specialised surface features that meet the needs of today's eco-conscious consumers.

The above-mentioned structural characteristics are critical components in facilitating increased consumer acceptance in the sustainable fashion sector. Attitudes and purchase intentions are recognised as the primary behavioural outcomes in consumer behaviour studies that link assessments of materials to potential consumption behaviours. Essentially, although consumers recognise the sustainability characteristics associated with a particular fashion accessory, attitudes toward those sustainability characteristics do not always equate to purchase intentions. Instead, consumers first establish an overall attitude towards a product that then determines subsequent purchasing behaviour related to the product. Recent trends in consumer preferences indicate that purchase intentions regarding eco-friendly accessories are highly dependent upon perceived quality and encompass aspects such as aesthetic appeal, durability, and maintaining their shape/form and structure throughout repeated loading or usage (Leonidou et al., 2022). Although a positive

attitude toward sustainable clothing typically results in strengthened purchase intentions, these relationships are weakened by concerns regarding aesthetics and uncertainty surrounding the functionality of a product (Rausch & Kopplin, 2021).

Environmental sustainability beliefs represent a key driver of consumers' willingness to participate in adopting sustainable products and environmentally conscious behaviours. Past research indicates that individuals who experience higher levels of interconnectedness are more likely to believe positively regarding environmental sustainability than others. Conversely, religiosity has demonstrated a significant inverse relationship with beliefs concerning environmental sustainability (Leonidou et al., 2022). Additionally, greater sustainability belief has been identified as resulting in increased involvement in environmental activism, thereby contributing to improved perceptions of quality of life. These findings support the premise that consumers engaging in pro-environmental behaviours may be more willing to accept sustainable fashion products and the benefits attributed to their sustainability.

Through fulfilling the aforementioned fundamental physical performance criteria while providing a legitimate Sarawakian cultural heritage storyline to the material composition of the fabric, the textile successfully responds to today's consumer demand for sustainable products combining functionality and cultural identity. As such, this integration contributes to shaping consumer perceptions by demonstrating that natural non-woven materials can provide both environmental advantages and adequate structural performance. By systematically evaluating how fibre blends behave when moulded over structural inserts, this research offers a clear pathway for translating raw regional biomass into high-value, consumer-accepted, sustainable fashion items. To address these challenges systematically, this study aims to evaluate the effect of bamboo culm grading on fibre morphology and extraction efficiency, determine the optimal bamboo-wool blend ratio for dimensional stability and softness, assess the tensile performance of the developed nonwoven textiles, and evaluate consumer acceptance of bamboo-based fashion accessories. This study presents a novel craft-engineering framework that systematically links bamboo culm grading, low-impact alkaline extraction, and the performance of a wet-felted bamboo-wool composite for sustainable accessory applications.

2. METHODOLOGY

This research examines the extraction process and potential applications of bamboo fibres derived from three grades (A, B, C) of *Bambusa longissima* obtained from Sarawak, Malaysia.

2.1 Research Design

This study adopted a quantitative research design. This study adopted a quantitative research design encompassing bamboo fibre preparation, low-impact extraction, the fabrication of nonwoven textiles through wet felting, laboratory-based material testing, prototype development, and market acceptance evaluation.

2.2 Raw Material Preparation and Bamboo Fibre Extraction

2.2.1 Bamboo Grading

The bamboo culms used were fresh *Bambusa longissima*. *Bambusa longissima* was selected because it is one of the most widely used types of Bamboo found in Sarawak, Malaysia, and has a fast-growing rate, high fibre production, and large amounts of fibre bundles, which can be applied for textiles. Several previous studies report that *Bambusa* species have favourable cellulose contents and fibre morphologies to use as a natural fibre extractant and textile reinforcement application. This species is also abundant locally, which makes this an excellent option to develop sustainable materials for possible commercial scale. These fibres were extracted by removing them mechanically after stripping the outer exodermis layer of bamboo culms. Fresh *Bambusa longissima* culms were obtained from the Sabal Forest Reserve located in Sarawak, Malaysia. Mature culms about 2-3 years old were chosen based on the colour of the external surface of the culm, the hardness of the culm, and harvest recommendations that are common practices when extracting fibres. Three gradations were made of each sample of bamboo culms for systematic evaluation of fibre extraction behaviour. The thickness of each sample was taken with a digital calliper at three different points on each sample. The average thickness was then used to classify each sample as Grade A, Grade B, or Grade C, as seen in **Table 1**. Each sample was then opened lengthwise to allow separation of the fibres. The Grade A bamboo had a thin wall (about .05 cm) and a larger pore structure than Grades B and C, which contained much thicker and denser walls (about 1.20- 1.50 cm) containing a tighter fibre bundle.

2.2.2 Pre-treatment and Alkaline Extraction

The treatment was carried out for the removal of non-cellulosic components such as lignin and hemicellulose without affecting fibre integrity. Coarse fibres were further softened with secondary mild alkaline treatment, if required. Before non-woven textile manufacturing, all fibres were washed, neutralised, and air-dried. The extraction of bamboo fibres was carried out using a controlled alkaline water bath method, modified from previous bamboo fibre extraction studies. Before chemical treatment, bamboo strips were soaked for 24 h at three different temperatures, 0 °C, 25 °C, and 100 °C, to analyse the effect of thermal softening before chemical treatment on natural fibres without any synthetic binder, as shown in **Figure 1**. The bamboo

strips were immersed in an alkaline solution containing 2 wt.% NaOH, 2 wt.% NaHCO₃, and 1 wt.% H₂O₂ at a liquor ratio of 1:20 (fibre-to-solution, w/v). The treatment was conducted at 80°C for 60 min in a thermostatically controlled water bath. Following treatment, the fibres were thoroughly rinsed with distilled water until the pH was neutral, then air-dried at room temperature for 24 h.

Table 1: Bamboo grading

Grade	Wall Thickness (cm)	Pore Density	Fibre Characteristics
A	<0.7	High	Looser fibre bundles, larger pore structure, easier fibre separation
B	0.7–1.1	Medium	Moderate fibre density and pore structure
C	>1.1	Low	Dense fibre bundles, compact structure, and more difficult fibre separation

2.2.3 Fibre Blending and Wet Felting Fabrication

Australian wool roving and organic cotton fibres were used as blending materials during non-woven fabrication. The refined bamboo fibres were mixed with wool and cotton fibres in various proportions such as bamboo–wool (BW), bamboo–cotton (BC), and bamboo–wool–cotton (BWC) systems. The fibres were disposed of regularly in layered structures on a bubble-wrapped surface. Soapy water was used to warm and swell the fibres, thereby entangling them. Mechanical rolling, pressure application, and repeated agitation were performed to achieve bonding between fibres and consolidation of the fibres into textiles. These felts were then washed with a weak acidic solution to remove any unabsorbed alkalinity and then dried in the air at room temperature. Preliminary trials were conducted using bamboo–wool, bamboo–cotton, and bamboo–wool–cotton blends. Fibre cohesion and handling performance were assessed qualitatively by three independent evaluators, based on uniformity, compactness, and felting stability. Bamboo–wool blends consistently demonstrated superior fibre entanglement, lower shrinkage variation, and improved structural integrity compared with the other formulations. Therefore, bamboo–wool blends were selected for fibre separation efficiency. The summary of the blend composition, specimen dimensions, and shrinkage values of the non-woven textiles produced is given in the following sections.

The initial 50/50 bamboo-wool ratio was selected as a balanced formulation to maximise bamboo content while maintaining sufficient wool fibre entanglement required for wet felting. Ratios were calculated based on dry fibre mass. All blend ratios reported in this study are expressed as dry fibre weight percentages. Linear

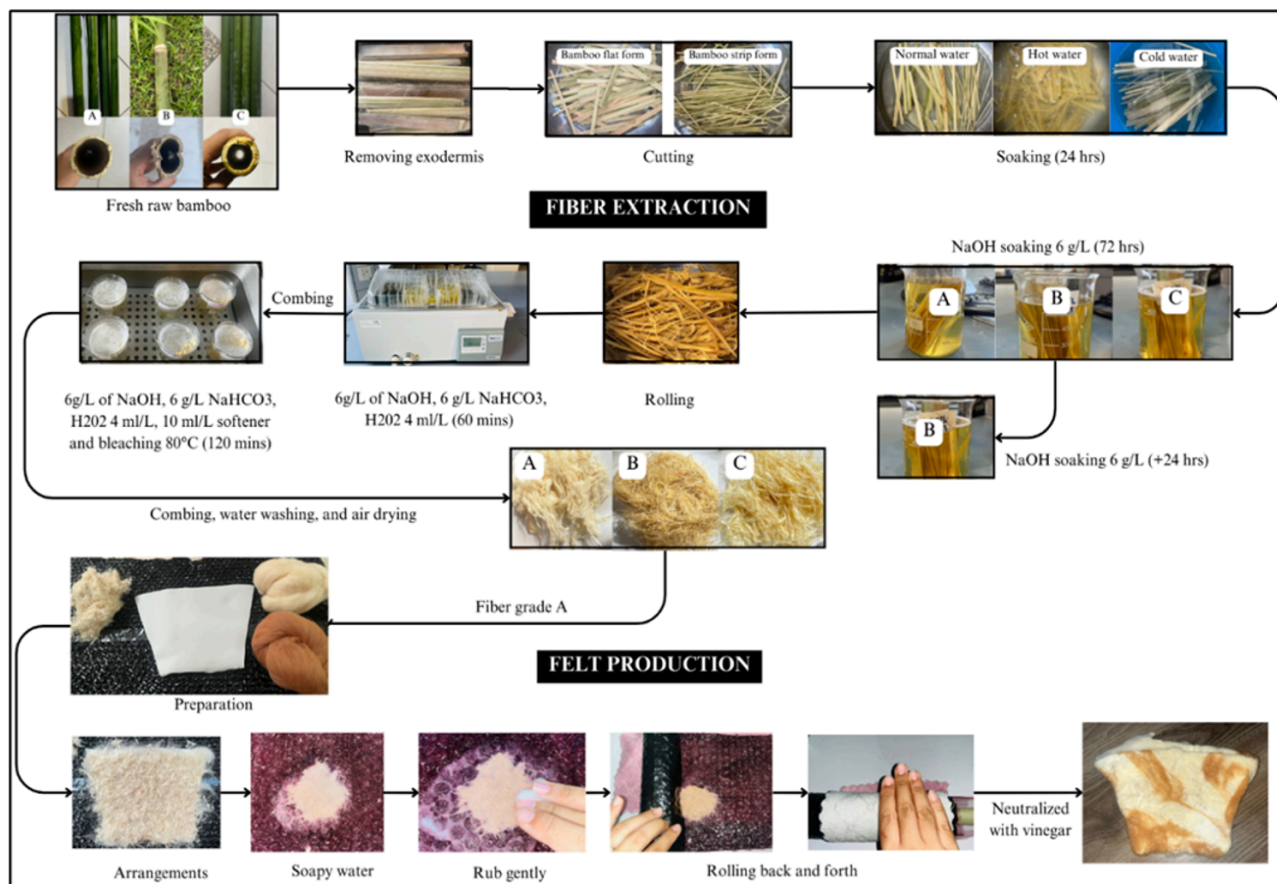


Figure 1: Schematic of sustainable bamboo textiles in each step from fibre extraction to felting production

shrinkage (%) was calculated based on the dimensional change of the specimens before and after drying using Equation (1):

$$\text{Linear Shrinkage (\%)} = [(L_{\text{wet}} - L_{\text{dry}})/L_{\text{wet}}] * 100 \quad (1)$$

where L_{wet} and L_{dry} represent the specimen dimensions (length or width) measured before and after drying, respectively; the mean Linear Shrinkage (%) was selected as the primary indicator of dimensional stability because it provides a balanced representation of shrinkage behaviour in both length and width directions. Before testing, all specimens were conditioned at $21 \pm 2^\circ\text{C}$ and $65 \pm 2\%$ relative humidity for 24 h.

2.2.4 SEM Analysis

Surface morphology and bonding behaviour between the fibres of bamboo fibre and non-woven textile samples were investigated by SEM (JSM-6390LA, JEOL, Malaysia). Samples were sputter-coated prior to analysis and observed at an accelerating voltage of 10 kV with magnifications up to 100 $\times$. The surface characteristics, pore distribution, fibre separation quality, and fibre connectivity of non-woven textile structures were

assessed using SEM analysis.

2.2.5 Shrinkage and Tensile Testing

The mechanical property of non-woven textiles was tested by a universal testing machine (Shimadzu AGS-X, 50 kN) according to ASTM D5035-11 (2019) standards. For each textile condition, 10 specimens were tested. The breaking force (N) and elongation at break (mm) were collected to evaluate tensile performance and behaviour (25 mm $\times$ 150 mm. Ten replicates (N = 10) were tested for each specimen type. To account for variations in basis weight, tensile strength was normalised by specimen mass and reported as specific strength (N/g). Statistical significance was evaluated using one-way ANOVA followed by Tukey's HSD test ($p < 0.05$). Mechanical and dimensional stability tests were conducted with 10 replicates per condition, and SEM observations were performed on representative specimens. All data are presented as mean $\pm$ SD. Dimensional stability tests employed were for measurements of dimensions before and after the felting and drying operations. Percentages of shrinkage were computed to evaluate the dimensional performance of various fibre blends. Quantitative image analysis of

fibre diameter and pore size was not conducted and is recommended for future work.

2.2.6 Prototype Development

The development of bamboo-based fashion accessories followed an iterative, studio-based research methodology that integrated the traditional art of wet-felting with systematic mechanical evaluation across four key stages. First, the process began with fibre optimisation, where Grade A bamboo fibres were chosen because of their thinner cell walls, wider lumens, and superior felting propensity. Based on prior experimental results, these fibres were blended with an equal mix of 50% wool and 50% cotton to achieve the best possible combination of softness and structural integrity. Next, during the forming and shaping stage, lightweight EVA moulds were manufactured to produce the same consistent shapes required for creating wearable products. The bamboo-wool felted layers were placed over these moulds, allowing for precision fitting to the wearer since the layers could be reshaped during the final stages of manual agitation. Finally, the assembly and finishing stage secured the felted layer to the EVA core using small amounts of textile-appropriate adhesives. Manual reinforcement stitching was also included in high-load areas, including strap and fastener sections, to provide additional support and convert the handcrafted prototype into a fully functioning accessory.

In addition to these factors, the following factors were used to test the prototype's overall performance: Tensile Testing (ASTM D5035-11), Shrinkage Tests to determine whether the accessories will maintain their shape after exposure to moisture or humid environments, and Trinocular Stereo Microscopy to measure fibre interlocking density, thereby demonstrating the difference between "correct" and "random" mixing techniques qualitatively. Statistical Analysis using SPSS was conducted. Cronbach's Alpha was used to establish internal reliability. Pearson Correlation Coefficients were calculated to examine the relationship between the constructs. Multiple Linear Regressions were run to demonstrate how both sustainability and aesthetics contribute to purchase intentions. Independent-Sample t-tests and a One-Way ANOVA were utilised to investigate demographic differences and differences in purchasing intent behaviours among respondent groups.

2.3 Market Acceptance

2.3.1 Sampling Strategy, Participant Profile, and Prototype Presentation Protocol

A purposive sampling method was used to gather participants (N = 120) representing Generation Z & Millennials, the main drivers of sustainable fashion consumption. A real-time product showcase was set

up to allow participants to receive tangible sensory input. Participants physically interacted with prototypes (handled them, felt them, etc.), visually examined the prototypes prior to completing survey questions regarding perceived softness and construction of materials. Participants had access to actual prototypes rather than simply viewing static pictures, therefore allowing participants to develop accurate perceptions of tactile attributes (fabric softness, structural thickness, mass, compression, and stitch quality) of prototypes before completing questionnaires.

2.3.2 Instrumentation, Construct Development, and Ethical Procedure and Consent

The quantitative assessment tool was organised into two major categories: demographic characteristics and constructs from existing literature measuring psychological constructs. The psychological section measured three constructs derived from current consumer behaviour literature. First, Sustainability Perception (three items) assessed participants' self-perceived environmental knowledge, perceived ecological value of products produced using this technology, and perceived circularity of materials. Second, Aesthetic Appeal (two items) measured participants' assessments of visual design uniqueness, style choice options, and current trend relevance of prototypes. Third, Purchase Intention (three items) measured participants' expressed behavioural readiness to buy products produced using this technology, willingness to pay for such products, and preferred raw material. All psychological items were rated using standardised 5-point Likert-type scales ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). All aspects of the research involved adherence to rigid ethics guidelines. Participation was completely voluntary, and every participant received an explanation document explaining the purpose of the study. Each participant signed a written informed consent prior to interacting with the prototype(s) and collecting data. Data confidentiality and complete anonymity were maintained throughout data collection and processing activities; No personally identifiable data/information was collected.

3. RESULTS

3.1 Phase One: Bamboo Fibre Characterisation and Grading

Clear differences were observed among the three grades (A, B, C) of *Bambusa longissima* culms, which affected fibre extractability and quality. Grade A bamboo, with thinner walls and larger pores, responded better to hot alkaline treatment and produced finer, softer, and more flexible fibres suitable for non-woven textiles. Grades B and C had thicker walls and denser vascular bundles, requiring more intensive processing. Pre-soaking at 100 °C improved fibre softening across all grades, although Grade A consistently showed

better processing efficiency and textile performance. SEM analysis also confirmed that bamboo morphology influenced fibre quality and inter-fibre bonding (**Figure 2**).

Although SEM analysis provided valuable information on fibre morphology (**Table 2**) and inter-fibre bonding

behaviour, quantitative image analysis of fibre diameter, pore size distribution, and fibre orientation was not conducted in the present study. Future work should incorporate image analysis software to obtain quantitative microstructural parameters and further correlate morphology with mechanical performance.

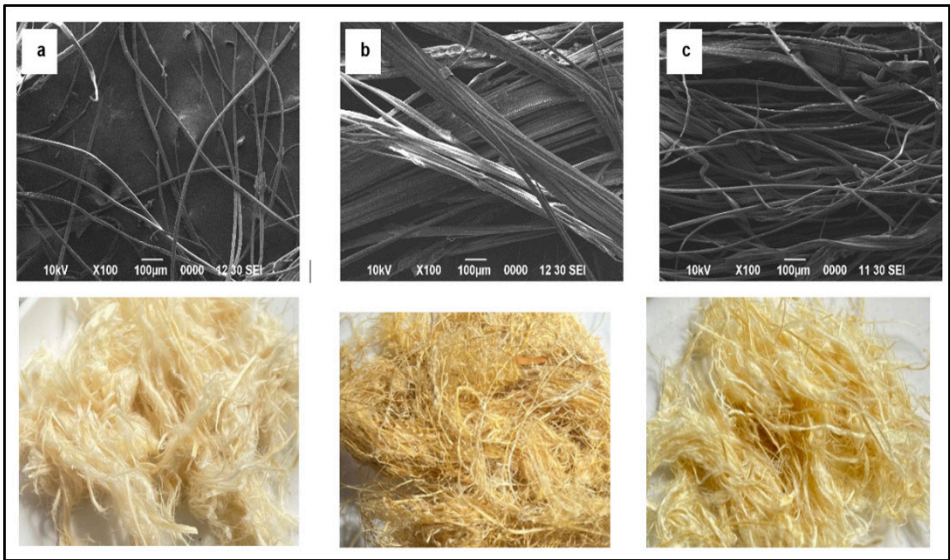


Figure 2: SEM micrographs of bamboo fibre in 100 µm: (a) Grade A; (b) Grade B; (c) Grade C

Table 2: Comparative SEM morphological assessment of bamboo-based non-woven textile blends

Sample	Fibre Separation	Fibre Entanglement	Fibre Distribution Uniformity	Apparent Pore Structure	Morphological Assessment
SW (100% Wool)	Moderate	Very High	Uniform	Moderate	Dense wool fibre network with strong inter-fibre entanglement
SB (100% Bamboo)	High	Low	Moderate	Large pores	Individual bamboo fibres are clearly separated with limited fibre interlocking.
SC (100% Cotton)	Moderate	Moderate	Uniform	Small pores	Compact fibre arrangement with relatively dense packing
BW-1 (50% Bamboo: 50% Wool)	High	High	High	Moderate	Well-balanced fibre network showing effective bamboo–wool interlocking
BC-2 (50% Bamboo: 50% Cotton)	Moderate	Moderate	Moderate	Moderate	Fibre blending observed, but with less inter-fibre cohesion than wool blends.
BCW-3 (33% Bamboo: 33% Cotton: 33% Wool)	High	High	Moderate	Moderate	Complex fibre network with mixed fibre interactions
BW-4 (40% Bamboo: 60% Wool)	High	Very High	High	Small–Moderate	Dense entanglement resulting from increased wool content
BW-5 (30% Bamboo: 70% Wool)	Moderate	Very High	High	Small	Compact fibre structure with strong fibre interconnectivity
BW-6 (20% Bamboo: 80% Wool)	Moderate	Very High	High	Small	Highly consolidated wool-dominated network with reduced pore space
BW-7 (70% Bamboo: 30% Wool)	High	Moderate	Moderate	Large	More open structure due to higher bamboo fibre proportion

Figure 3 presents the SEM micrographs of the various non-woven textile blends, illustrating differences in fibre distribution, pore structure, fibre separation, and inter-fibre entanglement. Distinct morphological variations were observed among the samples depending on fibre composition. The pure bamboo sample (SB) exhibited relatively separated fibres and larger pore spaces, indicating limited natural fibre interlocking. In contrast, the pure wool sample (SW) displayed a dense and highly entangled fibre network, reflecting the superior felting capability of wool fibres. The bamboo-wool blends showed improved fibre interconnectivity and more uniform fibre distribution compared with bamboo-only and bamboo-cotton systems. In particular, the BW-1 (50% bamboo:50% wool), BW-4 (40% bamboo:60% wool), and BW-5 (30% bamboo:70% wool) samples demonstrated compact fibre arrangements with enhanced fibre entanglement and reduced pore spaces, suggesting stronger internal bonding and improved structural stability. The increased wool

content contributed to greater fibre cohesion, as the natural scale structure of wool fibres promotes mechanical interlocking during the wet felting process. Conversely, the bamboo-cotton blend (BC-2) exhibited less compact fibre packing and lower fibre cohesion, indicating weaker inter-fibre bonding.

3.2 Phase Two: Mechanical Performance and Product Fabrication

Sample shrinkage, as shown in **Table 3**, varied clearly among the non-woven samples. Pure bamboo fabric (SB) showed no shrinkage, while pure cotton (SC) showed the highest shrinkage. Bamboo-wool blends with higher wool content generally showed greater shrinkage, whereas blends with higher bamboo content showed less deformation. Bamboo-cotton blends behaved similarly to cotton, indicating that bamboo had a limited effect on reducing cotton shrinkage. The bamboo-cotton-wool blend (BCW-3) showed moderate shrinkage and improved structural stability.

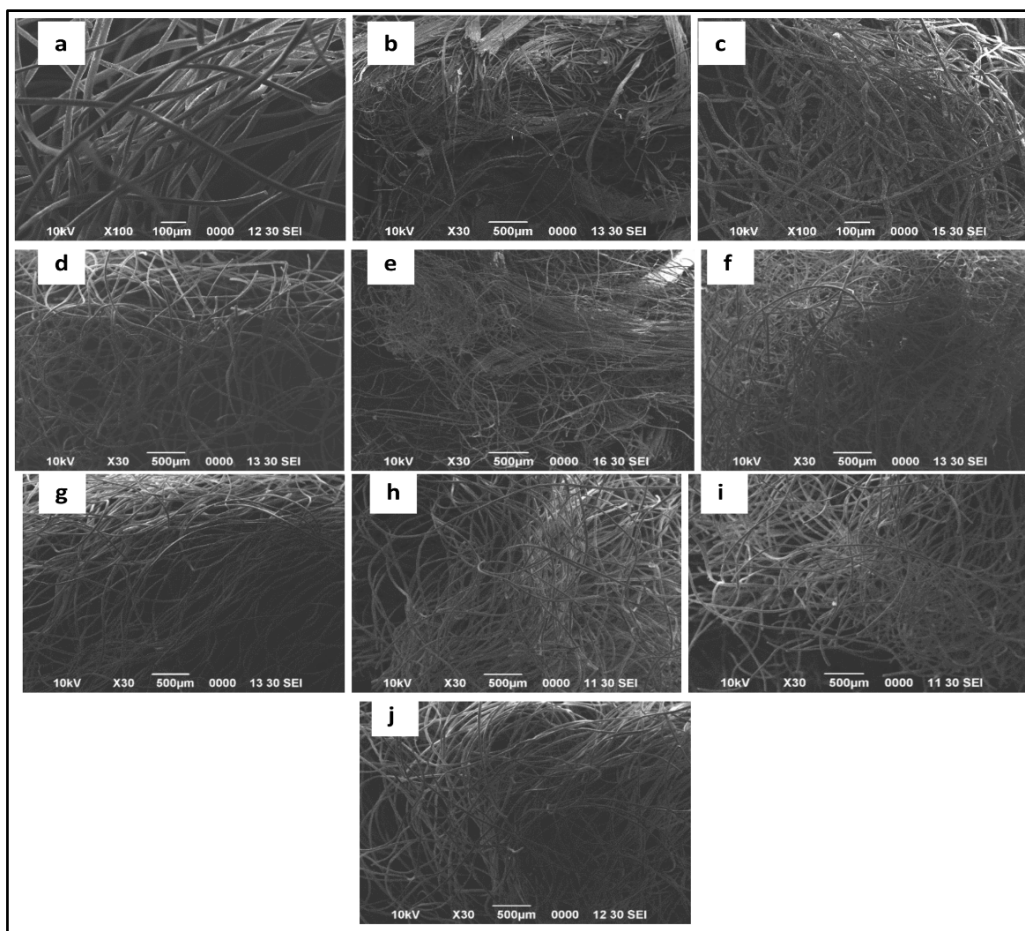


Figure 3: SEM micrographs of non-woven textile samples at magnifications of 30× and 100× showing fibre morphology, fibre distribution, pore structure, and inter-fibre entanglement: (a) SW (100% wool); (b) SB (100% bamboo); (c) SC (100% cotton); (d) BW-1 (50% bamboo:50% wool); (e) BC-2 (50% bamboo:50% cotton); (f) BCW-3 (33% bamboo:33% cotton:33% wool); (g) BW-4 (40% bamboo:60% wool); (h) BW-5 (30% bamboo:70% wool); (i) BW-6 (20% bamboo:80% wool); (j) BW-7 (70% bamboo:30% wool)

The mechanical performance of bamboo–wool non-wovens was significantly affected by cotton lining and fibre orientation. Lined samples had significantly higher breaking forces than non-lined samples ($p < 0.05$). Specifically, the 'Proper' fibre-mixing method resulted in a 34.6% increase in peak force compared with the 'Random' method, suggesting that systematic fibre alignment enhances load-bearing capacity in the Machine Direction (MD). While the lined samples provided superior specific strength, reaching 27.2 N/g, the reduction in elongation indicates that the lining acts as a structural constraint. Conversely, the non-lined samples displayed higher elongation (>25 mm), confirming that the absence of a rigid lining promotes greater material compliance, suitable for flexible wearable applications. The 50/50 bamboo–wool non-woven fabric was therefore the most suitable for wearable fashion accessories, while cotton reinforcement was more appropriate for rigid accessory applications.

Tensile properties, as shown in **Table 4**, were found to be very different between the non-woven samples. The tensile analysis revealed that fibre orientation and reinforcement significantly influenced mechanical performance. The properly mixed 50/50 bamboo–wool blend with a cotton lining (BW-P-L) exhibited the highest specific strength (27.2 ± 0.9 N/g), which was

significantly higher than all other configurations ($p < 0.05$). The MD samples showed greater resistance to deformation than the CD samples, consistent with the directional fibre alignment inherent in nonwoven manufacturing. The use of a cotton lining provided a synergistic reinforcement effect, effectively bridging the fibre matrix and increasing the breaking force, as evidenced by the clear statistical separation (a, b, c, d) between lined and non-lined samples.

Bamboo fashion accessories were successfully developed using a 50/50 bamboo–wool blend with cotton lining, as shown in **Figure 4**. In alignment with ethical research standards and to transparently acknowledge the assistance of generative AI tools in the development and documentation process, the final prototypes are presented using an AI-generated model, as shown in **Figure 4**, which is declared by the authors in this manuscript. This approach ensures a clear visual demonstration of the accessories' appearance, fit, and functionality while adhering to ethical standards for the presentation of the study's findings. Based on the Phase One analysis, Grade A bamboo was selected for prototype fabrication due to its superior softness and flexibility. Bamboo 50/50 felt showed better softness, dimensional stability, and less shrinkage than the pure woollen felt.

Table 3: Physical characteristics and dimensional stability of bamboo-based non-woven textile blends (mean $\pm$ SD, $n = 10$)

Specimen	Blend Composition (% dry fibre mass)	Weight (g)	Wet Length (cm)	Dry Length (cm)	Wet Width (cm)	Dry Width (cm)	Length Shrinkage (%)	Width Shrinkage (%)	Mean Linear Shrinkage (%)
SW	Wool (100%)	3.0 ± 0.1	8.7 ± 0.2	8.0 ± 0.2	5.0 ± 0.1	4.7 ± 0.1	8.0 ± 0.5	6.0 ± 0.4	7.0 ± 0.4
SB	Bamboo (100%)	3.0 ± 0.1	5.4 ± 0.1	5.4 ± 0.1	3.0 ± 0.1	3.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
SC	Cotton (100%)	3.0 ± 0.1	5.1 ± 0.1	4.6 ± 0.1	3.8 ± 0.1	3.3 ± 0.1	9.8 ± 0.6	13.1 ± 0.8	11.5 ± 0.7
BW-1	Bamboo 50%: Wool 50%	7.2 ± 0.3	7.2 ± 0.2	7.0 ± 0.2	4.6 ± 0.1	4.6 ± 0.1	2.8 ± 0.2	0.0 ± 0.0	1.4 ± 0.1
BC-2	Bamboo 50%: Cotton 50%	7.8 ± 0.3	7.8 ± 0.2	7.1 ± 0.2	3.8 ± 0.1	3.7 ± 0.1	8.9 ± 0.5	2.6 ± 0.2	5.8 ± 0.3
BCW-3	Bamboo 33%: Cotton 33%: Wool 33%	6.6 ± 0.2	6.6 ± 0.2	6.2 ± 0.2	5.1 ± 0.1	5.0 ± 0.1	6.1 ± 0.4	1.9 ± 0.1	4.0 ± 0.2
BW-4	Bamboo 40%: Wool 60%	6.9 ± 0.2	6.9 ± 0.2	6.0 ± 0.2	5.9 ± 0.1	5.5 ± 0.1	13.0 ± 0.8	6.8 ± 0.4	9.9 ± 0.6
BW-5	Bamboo 30%: Wool 70%	9.0 ± 0.3	9.0 ± 0.3	7.8 ± 0.2	7.2 ± 0.2	6.7 ± 0.2	13.3 ± 0.9	6.9 ± 0.4	10.1 ± 0.7
BW-6	Bamboo 20%: Wool 80%	8.3 ± 0.3	8.3 ± 0.3	7.7 ± 0.2	6.3 ± 0.2	5.4 ± 0.2	7.2 ± 0.5	14.3 ± 0.9	10.8 ± 0.7
BW-7	Bamboo 70%: Wool 30%	8.9 ± 0.3	8.9 ± 0.3	8.7 ± 0.2	7.9 ± 0.2	7.7 ± 0.2	2.2 ± 0.1	2.5 ± 0.2	2.4 ± 0.1

Note: Data are expressed as mean $\pm$ SD ($n = 10$). Shrinkage was calculated based on the linear change in specimen dimensions.

Table 4: Tensile properties of non-woven handmade textile blends (mean $\pm$ SD, $n = 10$)

Specimen	Configuration	Direction	Peak Force (N)	Elongation (mm)	Specific Strength (N/g)
BW-P-L	Bamboo/Wool (50/50) Proper + Lining	MD	451.8 ± 22.6	19.6 ± 0.9	27.2 ± 1.4
BW-R-L	Bamboo/Wool (50/50) Random + Lining	MD	335.5 ± 16.8	15.6 ± 0.8	20.1 ± 1.0
BW-P	Bamboo/Wool (50/50) Proper	CD	66.5 ± 3.3	25.2 ± 1.3	4.0 ± 0.2
BW-R	Bamboo/Wool (50/50) Random	CD	46.4 ± 2.3	31.7 ± 1.6	2.8 ± 0.1

Note: Specific strength calculated as (Peak Force / Weight).



Figure 4: Handcrafted bamboo-wool fashion accessories (Left: AI-generated image, Right: Original photography by authors)

As in previous studies, bamboo fibres added to the textile blends helped to increase flexibility and structure. While 100% bamboo materials showed the highest dimensional stability, bamboo–wool composite materials offered a better overall balance of strength, softness, and aesthetic properties, making them suitable for fashion accessories.

3.3 Phase Three: Market Acceptance Quantitative Metrics

The sample comprised 55.8% female and 44.2% male respondents. The occupational distribution included government workers (25.8%), students (24.2%), self-employed individuals (24.2%), and entrepreneurs (17.5%). Before the evaluation, 80.8% of the respondents expressed awareness of sustainable fashion, and 71.4% were familiar with bamboo-based textile alternatives, ensuring an informed respondent base capable of evaluating product innovations. This means a customer base that is already predisposed with enough awareness about the eco-fashion concept, which makes it possible to gauge product perception and purchase behaviour with assurance. Results indicated that aesthetic value is still the key factor for the consumers' preferences. 60.8% of respondents chose aesthetic appeal and uniqueness, while sustainability considerations came in second at 43.3%. This further validates that, although the importance of environmental values cannot be denied, visual and design-related attributes remain the primary factors in fashion accessory consumption. The purchase motivation analysis supports this trend. Stylish and trendy design was the top driver (53.3%), followed by sustainability awareness and education (46.7%).

By comparison, external marketing factors such as salespeople recommending the product (5.0%) and

being available in stores (15.8%) had a minor effect. This indicates that the motivation of the consumer to use accessories made of bamboo is mostly intrinsic motivation and not from promotion. Willingness-to-pay analysis indicates a possible market position in the middle range. Over half of respondents would be willing to pay USD 31–50 for bamboo accessories, and 11.7% would be willing to pay more than USD 50. This validates the notion that there is a price premium for sustainable fashion products when design quality and perceived value are high. The results of the product evaluation indicate exceptional market acceptance. Overall, 92.5% of respondents said they would recommend the product, and 99.2% of respondents said they were interested in the overall market.

Design variety (46.7%), sustainability information (30.0%), and better availability (30.0%) led the purchase encouragement factors. The results show that design innovation and clear sustainability communication will be key in achieving maximum uptake. The respondents had a high level of sustainability consideration ($M = 4.39$) and bamboo as an alternative material ($M = 4.41$). Material preference ($M = 4.50$) and purchase intention ($M = 4.47$) suggest a high level of behavioural readiness for adoption. The situation of bamboo textiles is, however, the contrary; familiarity is still relatively low ($M = 3.01$), which reflects the “awareness – familiarity gap” of bamboo textiles. This implies that consumers have grasped the need for sustainable materials, but there are only limited chances of exposure and familiarity with them, which will be a crucial hurdle for market scaling. In addition, the aesthetic evaluation ($M = 4.19$) and perceived durability ($M = 4.20$) further reinforce the positive perception of the product, indicating that both

functional and hedonic attributes play an important role in fostering product usage. Results for reliability testing indicate that all constructs have high internal consistency. The Cronbach's α values of Sustainability Perception ($\alpha = 0.812$), Aesthetic Appeal ($\alpha = 0.795$), and Purchase Intention ($\alpha = 0.834$) are greater than the recommended a value of 0.70, which reflects a reliable measurement structure.

As detailed in **Table 5**, all individual scales exceeded the universally accepted reliability threshold of $\alpha = 0.70$, and the entire instrument demonstrated strong structural validity ($\alpha = 0.884$).

Table 5: Instrument reliability and scale internal consistency ($N = 120$)

Construct Scale	Included Survey Items	Number of Items	Cronbach's Alpha (α)
Sustainability Perception	Knowledge of Environmental Benefits, Sustainability Considerations, and Product Perception	3	0.812
Aesthetic Appeal	Design and Aesthetic Appeal, Aesthetic Evaluation	2	0.795
Purchase Intention	Purchase Intention, Willingness to Pay, Material Preference	3	0.834

According to the Pearson correlation analysis, there are significant positive relationships among all constructs. Aesthetic Appeal ($r = 0.638$, $p < 0.001$) and Sustainability Perception ($r = 0.582$, $p < 0.001$) are the strongest correlations with Purchase Intention. The most important factor is Aesthetic Appeal ($\beta = 0.481$, $p < 0.001$), followed by Sustainability Perception ($\beta = 0.392$, $p < 0.001$). It is therefore confirmed that aesthetic quality is the most important factor influencing consumers' purchase behaviour for fashion accessories, with environmental values also being important. Multiple regression showed that Sustainability Perception and Aesthetic Appeal significantly predicted Purchase Intention, with an R^2 of 0.523 and an Adjusted R^2 of 0.515, and a p -value < 0.001 . Model diagnostics rule out multicollinearity as a confounding factor, as evidenced by stable Tolerance values above 0.823 and Variance Inflation Factors safely below 1.215. Examination of the standardised coefficients confirms that both parameters act as highly significant positive predictors, with Aesthetic Appeal emerging as the dominant driver ($\beta = 0.48$, $p < 0.001$) compared to Sustainability Perception ($\beta = 0.392$, $p < 0.001$). This statistical hierarchy confirms that while environmental values offer a necessary ethical baseline, visual design optimisation remains the definitive catalyst

for consumer conversion in the sustainable luxury accessory segment. Overall model parameters are $R^2 = 0.523$, Adjusted $R^2 = 0.515$, $F(2, 117) = 64.125$, $p < .001$.

Table 6 presents the results of inferential testing for differences in purchase intention among the demographic and behavioural groups. There was no difference between male and female respondents in the independent-samples t -tests ($p = 0.108$). Bamboo-based fashion accessories also have broad cross-gender appeal. Purchase intention, however, was found to be significantly influenced by prior sustainable purchasing experience ($p = 0.002$). The respondents who have been exposed to sustainable fashion showed lower perception of risk and more intention to purchase sustainable fashion products, which means that the higher the exposure, the greater their intention to purchase. According to the one-way ANOVA results, there was no significant difference in acceptance of Bamboo fashion accessories across age groups ($p = 0.222$), indicating uniform acceptance among younger and older consumers. This indicates consistency and uniformity in market opportunities across different segments.

Table 6: Multiple linear regression analysis

Predictor Variables	β	t	p -value	VIF
Sustainability Perception	0.392	5.216	< 0.001	1.215
Aesthetic Appeal	0.481	6.421	< 0.001	1.215

Note: $R^2 = 0.523$, Adjusted $R^2 = 0.515$, $F(2, 117) = 64.125$, $p < 0.001$.

4. DISCUSSION

While previous studies mainly investigated bamboo fibres for mechanical performance, the present study extends existing knowledge by integrating material engineering with consumer acceptance analysis, thereby providing a more comprehensive evaluation of commercial viability.

4.1 Morphological Influence on Fibre Extraction and Processing Efficiency

The data obtained through experiments in this study show that bamboo culm anatomy and raw material morphology have an impact on fibre extraction efficiency, subsequent textile strength, and the final use of the produced non-woven products for sustainable fashion uses. Compared to each other, the three different bamboo culm grades show that Grade A has a higher value of being processed sustainably because it has a thinner cell wall with high porosity. Due to its microporous architecture, there is more opportunity for deep, even penetration of low-concentration alkaline solutions to reach all parts of the bamboo culm matrix, so that pectin, hemicellulose, and structural lignin can be dissolved and removed from the matrix. Because of this, Grade A produces finer, much more flexible and

individualised fibres than do Grades B and C. On the other hand, due to their highly dense matrix structures, the chemical diffusion rates in Grades B and C are limited, which leads to less than complete breakdown of the matrix; residual fibre bundles remain after processing; the fibres tend to be coarser; and therefore, the overall process is much less efficient. The lower cumulative energy requirements for energy-intensive chemical treatments and prolonged mechanical processing used when utilising Grade A bamboo provide an additional benefit in terms of sustainability and lifecycle assessments. The structural advantages of using Grade A bamboo also allow for better utilisation of resources.

4.2 Microstructural Entanglement and Anisotropic Mechanical Synergies

Images taken from SEM provide valuable information about how the mechanically interconnected nature of the nonwoven web develops. These images clearly illustrate that in comparison to either single-component bamboo-cotton or bamboo-wool blends, the hybridisation of bamboo and wool creates significantly higher levels of entanglements per unit area as well as more favourable inter-fibre bonding configurations. This synergistic relationship occurs due to the combination of two types of fibres, where bamboo serves as a structural scaffold providing rigidity, while wool contributes flexibility and natural crimping, allowing for significant improvement in mechanical locking of fibres as well as increased entrapment at the microscopic level during manual wet felting agitation. As a result of these highly cooperative interactions between component fibres, greater cohesion exists among the fibres in the non-woven web; higher density exists in the fabric; and therefore, longer-term dimensional stability exists in the non-woven textile structure, all without incorporation of synthetic chemical binding agents or petroleum-based reinforcement materials. Therefore, hybridising complementary biomass fibres is a viable method to increase the mechanical properties of non-woven natural fabrics, while maintaining their inherent biodegradable and environmentally compatible properties. Also important to note is that the extent of entanglement between fibres, as well as uniformity of fibre networks, plays a large role in determining the directionally dependent tensile behaviour as well as long-term dimensional stability of non-wovens. Samples developed with denser fibre networks and fewer internal void areas were consistently demonstrated to possess superior structural integrity, uniform distribution of stresses applied to the sample during testing, and greater resistance to deformation of the sample during both wet felting and subsequent heat drying cycles.

4.3 Dimensional Stability and Linear Shrinkage Optimisation

A major accomplishment of this research has been the significant reduction in dimensionally-shrinkable

properties among the engineered bamboo-wool composite blends. This property reaches its maximum at the optimised 50/50 blend ratio. Bamboo fibres present a linear and extremely stiff morphology to function as a stabilising anchor within the complex felted matrix, thereby limiting the large shrinkage observed in pure wool felt systems. Due to their straight morphology and absence of surface scales, bamboo fibres do not experience progressive contraction or directional migration from moisture absorption or mechanical agitation under wet or drying conditions. Conversely, the entangled wool fibres supply the non-woven fabric with controlled elasticity, resiliency and elastic recovery. By providing a synergy between structural stiffness (bamboo) and elastic flexibility (wool), excellent dimensional stability and increased functionality and durability are provided. These performance characteristics are essential for commercially viable sustainable-fashion applications requiring long-term use by consumers. The optimised fibre system was also experimentally validated using the practical construction of functional bamboo-wool prototype examples. The creation of these functional prototypes illustrates that the engineered non-woven textile systems possess sufficient mechanical performance, mouldability and structural durability to support practical assembly, cutting, moulding, and finishing processing steps without matrix delamination or edge unravelling. Finally, the intentional pairing of Grade A bamboo fibres with the 50/50 bamboo-wool formulation provides a superior balance of tactile pliability, tensile strength, organic texture and durable shape retention necessary for high-end, handcrafted sustainable products.

4.4 Consumer Perception, Psychometric Modelling, And the Aesthetic-Attitude Gap

These results reflect the tenets of consumer culture theory, which states that individuals have a high level of environmentally-related knowledge; however, this knowledge does not automatically convert into actual behavioural changes. Therefore, there exists a clear attitudinal-behavioural gap where simply having environmental values will not lead to adoption. Instead, it is apparent that aesthetic gatekeeping is a critical intervening variable in determining whether a customer purchases sustainable-fashion products; i.e., aesthetic appeal is an important factor in determining what customers ultimately buy. Consumers rank visual identity, design excellence, self-expression, and environmental concerns relative to each other. Interacting physically with the prototypes can assist in reducing "green scepticism" and increasing confidence in product performance. This finding challenges the common assumption that environmental awareness alone drives sustainable purchasing behaviour. Instead, the results indicate that consumers evaluate sustainable fashion through both emotional and functional dimensions.

Therefore, successful commercialisation of bio-based textiles requires integrating sustainability with attractive design rather than relying solely on environmental messaging. From a marketing perspective, the results indicate that merely emphasising ecological messages regarding sustainable-fashion products is insufficient; instead, a value-added strategy must be employed that integrates sustainability into the design of the product rather than employing a value-first strategy in which sustainability is used as a sales message. The quantitatively derived findings related to the market acceptance assessment demonstrate favourable proof-of-commercial-feasibility and market potential for bamboo-based fashion accessories. The descriptive statistics illustrate a very positive sentiment towards sustainable-design-alternatives in clothing and an open-mindedness to bamboo apparel as an eco-friendly alternative to traditional resource-intensive clothing materials. The model-based psychometrics derived from this study indicate that physical appearance and/or visual aesthetic(s) are statistically better predictive variables of a customer's ultimate purchase intentions than environmental sustainability.

Although consumers recognise environmental responsibility as one of many key core values, the empirical data identified a group of four visual/hedonic product attribute categories that were found to be the most determinant factors in predicting consumers' ultimate purchasing behaviour: Visual Attractiveness, Stylistic Uniqueness, Design Excellence and Tactile Luxury. These findings provide insight into how current fashion marketing functions, indicating that sustainable material campaigns must incorporate both appealing/trendy product features and ecologically sound values in order to encourage successful purchases. Furthermore, parametric analysis indicated that consumers who reported previous experience purchasing sustainable garments exhibited greater intention to adopt these new prototypes than consumers without such previous experience. This difference in means indicates that increased exposure to eco-friendly material alternatives increases confidence in the performance-risk associated with these new materials, thereby increasing willingness to buy. Therefore, structured consumer education, strategic brand communication, and hands-on tactile experiences represent necessary operational actions to overcome the existing market gap and facilitate wide-scale commercial adoption of bamboo-based fashion innovations.

4.5 Regression Insights and Circular Design Frameworks

Sustainability is a critical element of the study. Although bamboo wool felt is biodegradable, we can say that the combination of the EVA moulds and adhesives has some level of sustainability, but does so at a cost. Because the EVA moulds have been selected for their durability, they should be reused for each production cycle. Using a

mould reuse strategy, we reduce the amount of waste created per unit. Synthetic binders also prevent us from being able to compost the entire product when the life cycle is completed. For future designs, we are looking at 'design for disassembly', which is going to give us less dependence on chemical adhesives. The statistical output of our multiple linear regression analysis validates the necessary complementary relationship between a consumer's sustainability perception and a product's aesthetic appeal in determining whether the product is validated for purchase. Sustainability perception is significantly supportive of purchasing decisions. Aesthetic Appeal was the greatest predictive variable in the equation. This hierarchy is consistent with the current body of literature surrounding sustainable fashion, which continues to show that issues of personal style, visual identity, and aesthetic self-expression continue to take priority among consumers. Environmental considerations act as secondary validating attitudes. As such, to actually compete in the marketplace and to address the well-known 'attitude-behaviour gap' in green consumption, sustainable textile development needs to move past simple ecological messages and look to create new innovative, avant-garde product designs. From a whole sustainability perspective, the engineered bamboo-based non-woven fabric demonstrated a good ability to contribute to circular fashion systems meaningfully. Bamboo is one of the lowest input agriculture footprints and requires no synthetic pesticides; additionally, it provides an extremely rapid, renewable carbon sink. Once all other fully biodegradable protein fibres like wool are added to bamboo, then we will allow for regionally manufactured low-impact, closed-loop material options for the worldwide textile industry. Additionally, using low-impact and low-concentration chemical extraction processes along with artisanal hand felting fabrication processes allows for both low-carbon and resource-efficient production processes that meet the requirements for strict ecological expectations of current sustainable fashion applications.

4.6 Craft-Industrial Integration and Cultural Heritage

In addition to purely scientific and mechanical performance measures, the utilisation of traditional hand felting techniques represents the effective incorporation of heritage crafts into modern sustainable industrial design paradigms. Even though explicit cultural preservation variables were not the main focus of this material testing study, adding regional cultural heritage, inspired by the low-impact and artistic material philosophies present in traditional crafts from Sarawak, Malaysia, adds a significant aesthetic story and distinct artisanal aspect to the final fashion pieces. The intersection of science and craft increases the possibilities for local, decentralised, highly sustainable production methods, challenging fast fashion's linear, high-waste paradigm. In short, the synthesised empirical

data demonstrate that bamboo-wool nonwoven textiles have tremendous opportunities as next-generation sustainable materials for the fashion accessory markets because of their great environmental performance, functional structural durability, desirable aesthetic attributes, and confirmed consumer acceptability. This study establishes a foundation for extracting, mechanically characterising, and crafting hand-felted bamboo-wool textiles. Several environmental and performance limitations need to be identified. First, characterisation of this material system as a 'low impact', 'sustainable' alternative is predicated upon the renewable and biodegradable nature of the raw bamboo and wool biomass as noted in the established literature. However, a rigorous quantitative verification, such as a formal LCA or comprehensive carbon footprint comparison to synthetic non-wovens, would have exceeded the scope of this initial design study. Second, although the mechanical-alkali processing utilises a lower concentrated solution than is common in many similar studies, a complete chemical residue and wastewater analysis is needed to optimise the environmental efficiency of the extraction stage. Thirdly, even though the physical properties and specific strength measures indicate optimal structure for fashion accessories, durability profiling testing for abrasion-resistant simulation test usage and standard biodegradation test for long-term durability still remain necessary. Future studies will focus on completing these empirical gaps to validate the full circular loop for engineered textiles.

The findings of this study show that developing viable, eco-friendly bamboo-based non-woven textiles requires balancing material structure, fibre engineering, mechanical durability, and consumer interest. By integrating material science, textile engineering, and sustainable design principles, the study reveals how bamboo's natural structure, fibre blends, and sustainable design principles determine the performance and market viability of bamboo-wool fabrics. The findings emphasise that evaluating bio-based materials requires looking beyond environmental perks to include both functionality and market appeal. From a materials perspective, the results show that bamboo culm structure directly affects fibre extraction and quality. The findings suggest that anatomical grading should be considered as a key criterion during raw material selection for sustainable textile manufacturing. Rather than relying solely on species identification, selecting bamboo according to culm morphology may improve extraction efficiency while simultaneously reducing chemical consumption and processing energy. This provides an important contribution toward resource-efficient production systems and supports sustainable material engineering. This aligns with the findings reported by Cao et al. (2022), who observed that more porous bamboo cell walls provide better chemical

accessibility and require less pretreatment than denser tissues. Consequently, the more compact structural makeup of Grades B and C likely hinders chemical diffusion, leading to less efficient fibre separation. Additionally, Zhang et al. (2024) showed that bamboo structural characteristics, including culm wall thickness, vascular bundle distribution, and the proportion of fibre sheaths and parenchyma cells, significantly influence its mechanical properties. Thicker culm walls containing a higher density of fiber-rich vascular bundles in thicker culm walls contributes to the superior mechanical performance of bamboo. Thus, anatomical grading offers a practical means of selecting raw materials that enhance fibre extraction efficiency while reducing chemical and energy consumption.

The SEM images demonstrated that the bamboo and wool fibres formed a tightly integrated structure without the use of synthetic binders. A combination of bamboo and wool forms a tightly integrated structure without synthetic binders. This finding demonstrates that natural fibre hybridisation can achieve adequate mechanical reinforcement without synthetic binders. Such an approach contributes to the development of biodegradable nonwoven materials and provides an alternative strategy for replacing petroleum-based reinforcement commonly used in commercial nonwoven composites. Bamboo possesses structural stiffness and load-bearing capability because of its high tensile stiffness and fibre-rich structure, as reported by Phongphinitana et al. (2025). In contrast, the natural crimp of wool fibres promotes fibre entanglement and flexibility, facilitating mechanical interlocking within the nonwoven matrix. The combination of these characteristics likely contributed to the formation of a stable fibre network, enhancing the structural integrity of the composite while maintaining flexibility. A 50/50 blend offers optimal dimensional stability, and successful fashion prototypes prove the material is both durable and mouldable enough for commercial production. Despite consumers expressing positive attitudes towards sustainability, the statistical analysis revealed that aesthetic appeal, tactile quality, and stylistic design are the strongest determinants of purchase intention. These results confirm the attitude-behaviour gap identified by Ying et al. (2025), who found that greater environmental awareness among Malaysian consumers does not automatically translate into eco-friendly buying decisions.

While consumers may express positive attitudes toward sustainability, the present study demonstrates that purchase intention is influenced more strongly by aesthetic appeal, tactile quality, and stylistic design than by sustainability attributes alone. This indicates that consumers evaluate sustainable fashion using both environmental and emotional factors, meaning how much they desire the product still heavily drives

their intent to buy. Consequently, to boost market success, sustainability must be integrated into products that also satisfy consumer expectations for design, quality, and style. The bamboo-wool non-woven textile developed in this study demonstrates how this can be achieved by combining sustainable materials with a low-impact manufacturing process that aligns with circular economy principles. Integrating modern fibre engineering with traditional hand-felting techniques preserves artisanal craftsmanship while encouraging decentralised, eco-friendly production as an alternative to fast fashion. To fully validate this material, future research must replace qualitative assessments with quantitative data, such as full LCA, biodegradation tests and durability metrics. Future work should also focus on scaling up fibre extraction and developing 100% biodegradable bonding agents to eliminate synthetic adhesives. Beyond confirming the mechanical suitability of bamboo-wool composites, this study contributes to sustainable textile research by integrating material characterisation, prototype development, and consumer acceptance within a single framework. This holistic approach demonstrates that successful adoption of bio-based fashion materials depends not only on material performance but also on consumer perceptions of aesthetics and functionality. The findings therefore provide practical guidance for researchers, designers, and manufacturers seeking to commercialise sustainable textile innovations.

5. CONCLUSION

The results show the first indication of a possible approach to create sustainable textiles from bamboo fibres by combining bamboo with wool through an optimised felted blend ratio. The structural stability of unprocessed bamboo fibres can be effectively combined with the elasticity of wool roving in an optimal 1:1 ratio to achieve the needed tensile strength properties and reduce the shrinkage of such a fibre web. The success of translating this fibre web into prototype garments has proven the feasibility of the process to produce functional and fashionable accessories made from a naturally occurring, non-synthetic composite. However, due to all manual processing methods used during this study, no assumptions regarding scale-up potential to industrial levels should be taken lightly and have been clearly identified as needing to be tested. Additionally, since there are currently no established scientific standards available to measure the 'green' nature of textiles based upon their raw materials alone, this research represents primarily speculative theory regarding the sustainability benefits of the proposed textile. Therefore, before it can be considered commercially viable, additional research needs to occur. Specifically, testing the durability (abrasion resistance, deformability) of this non-woven fabric after multiple simulated uses will provide insight into its

performance characteristics. In addition, a full life cycle assessment, including comparisons of greenhouse gas emissions produced during harvesting and production, analyses of the water quality impacts resulting from alkaline mechanical treatment of the bamboo during extraction, and assessments of other environmental impacts associated with each component, must also be completed. The last critical step necessary would be to conduct a large-scale survey to assess how well consumers accept the new product concept.

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DECLARATION OF COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Dhea Gusty Adelina: Conceptualisation, Methodology, Resources, Visualisation, and Writing – original draft.

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ARTIFICIAL INTELLIGENCE (AI) DECLARATION

During the preparation of this work, the author used ChatGPT (OpenAI, USA) as a language assistant to rephrase and refine the text. After using this tool, the author reviewed and edited the content as necessary, taking full responsibility for the publication's accuracy.

REFERENCES

- Aktaş, B. M., & Mäkelä, M. (2019). Negotiation between the maker and material: Observations on material interactions in the felting studio. *International Journal of Design*, 13(2), 55–67. <http://www.ijdesign.org/index.php/IJDesign/article/view/3267>
- Almalki, D. K., & Tawfiq, W. A. (2023). Implementation of a sustainable apparel design framework for felted women's garments made of local wool. *Fashion Practice*, 15(3), 401–423. <https://doi.org/10.1080/17569370.2023.2186033>
- Behera, D., Pattnaik, S. S., Nanda, D., Mishra, P. P., Manna, S., & Behera, A. K. (2025, January 1). A review of bamboo fibre reinforced composites and their

- potential applications. *Emergent Materials*. Springer Nature. <https://doi.org/10.1007/s42247-024-00832-9>
- Cao, M., Ren, W., Zhu, J., Wang, H., Guo, J., Zhang, X., & Yu, Y. (2021). Cell wall pore structures of bamboo as relation to species and tissue types. *Research Square*, 1–17. <https://doi.org/10.21203/rs.3.rs-1067748/v1>
- Chokshi, S., Parmar, V., Gohil, P., & Chaudhary, V. (2022). Chemical composition and mechanical properties of natural fibres. *Journal of Natural Fibres*, 19(10), 3942–3953. <https://doi.org/10.1080/15440478.2020.1848738>
- Debnath, S. (2017). Sustainable production and application of natural fibre-based nonwoven. In *Sustainable Fibres and Textiles* (pp. 367–391). Elsevier. <https://doi.org/10.1016/B978-0-08-102041-8.00013-5>
- Emamverdian, A., Ding, Y., Ranaei, F., & Ahmad, Z. (2020). Application of bamboo plants in nine aspects. *The Scientific World Journal*, 2020, Article 7284203. <https://doi.org/10.1155/2020/7284203>
- Ghalachyan, A. (2018). *Evaluation of consumer perceptions and acceptance of sustainable fashion products made of bacterial cellulose* [Doctoral dissertation, Iowa State University]. Iowa State University Digital Repository.
- Hu, M., Wang, C., Lu, C., Anuar, N. I. S., Yousfani, S. H. S., Jing, M., Chen, Z., Zakaria, S., & Zuo, H. (2020). Investigation on the classified extraction of the bamboo fibre and its properties. *Journal of Natural Fibres*, 17(12), 1798–1808. <https://doi.org/10.1080/15440478.2019.1599311>
- Hwui, K. C. Q., & Jalil, M. H. (2025). Reimagining indigenous material culture: Exploring and utilizing bamboo as a sustainable approach in contemporary costume design – A case study on Marik Empang beadwork. *Asian Journal of Arts and Culture*, 25(3), Article e287056. <https://doi.org/10.48048/ajac.2025.287056>
- Jalil, M. H. (2022). Eco-fashion design: A review. *International Journal of Sustainable Design*, 4(3–4), 205–233. <https://doi.org/10.1504/IJSDS.2022.128515>
- Jalil, M. H. (2025). Weaving a greener tomorrow: A mini review of bamboo fibre, textiles, and hand-woven techniques for sustainable innovation. *Pertanika Journal of Science & Technology*, 33(3), 1661–1682. <https://doi.org/10.47836/pjst.33.3.25>
- Javadian, A., Smith, I. F. C., Saeidi, N., & Hebel, D. E. (2019). Mechanical properties of bamboo through measurement of culm physical properties for composite fabrication of structural concrete reinforcement. *Frontiers in Materials*, 6, Article 15. <https://doi.org/10.3389/fmats.2019.00015>
- Kerr, J., & Landry, J. (2017). Pulse of the fashion industry. Global Fashion Agenda & The Boston Consulting Group. http://globalfashionagenda.com/wp-content/uploads/2017/05/Pulse-of-the-Fashion-Industry_2017.pdf
- Kumar, A., Sharma, K., & Dixit, A.R. (2019). A review of the mechanical and thermal properties of graphene and its hybrid polymer nanocomposites for structural applications. *Journal of Materials Science*, 54, 5992–6026. <https://doi.org/10.1007/s10853-018-03244-3>
- Leonidou, C. N., Gruber, V., & Schlegelmilch, B. B. (2022). Consumers' environmental sustainability beliefs and activism: A cross-cultural examination. *Journal of International Marketing*, 30(4), 78–104. <https://doi.org/10.1177/1069031X221128786>
- Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, 1(4), 189–200. <https://doi.org/10.1038/s43017-020-0039-9>
- Phongphinitana, E., Klangtup, N., & Jearanaisilawong, P. (2025). Mechanical properties of asymmetric woven bamboo structure from bamboo strips. *Fibers*, 13(2), Article 18. <https://doi.org/10.3390/fib13020018>
- Rausch, T. M., & Kopplin, C. S. (2021). Bridge the gap: Consumers' purchase intention and behaviour regarding sustainable clothing. *Journal of Cleaner Production*, 278, Article 123882. <https://doi.org/10.1016/j.jclepro.2020.123882>
- Rocky, B. P., & Thompson, A. J. (2018). Production of natural bamboo fibres-1: Experimental approaches to different processes and analyses. *Journal of the Textile Institute*, 109(10), 1381–1391. <https://doi.org/10.1080/00405000.2018.1482639>
- Ying, L. Z., Teck, T. S., Geok, L. S., Fernandez, R. T., Liao, C. H., & Sonar, P. (2025). Investigating the impact of consumer attitudes towards sustainable products, corporate sustainability, and green marketing on green consumption behavior in Malaysia. *Advances in Consumer Research*, 2(5), 2371–2379.
- Zhang, K., Yu, L., Dai, F., Chen, Y., Jiang, Z., Wang, Y., & Tian, G. (2024). Bamboo structure and its impact on mechanical properties: A case study of Bambusa arundinaceous. *Forests*, 15(5), Article 762. <https://doi.org/10.3390/f15050762>
- Zhao, W., Zhang, J., Zhang, W., Yuan, S., Chen, H., & Wu, A. (2023). Effect of bamboo unit morphology on the preparation of bamboo fibres by steam explosion. *Industrial Crops and Products*, 202, Article 117066. <https://doi.org/10.1016/j.indcrop.2023.117066>