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Innovative Integration of Modern Woollen Weaving Technology and Ruyuan Yao Patterns in Children's Clothing Design

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ABSTRACT

This study integrates traditional Ruyuan Yao motifs with modern woollen knitting to develop a child-wearable design framework. Thirty representative patterns were documented through fieldwork in Ruyuan Yao Autonomous County and reconstructed into a modular digital library; five garment sets were then fabricated using 12-gauge jacquard mapping and evaluated for cultural/semantic retention by Yao intangible-heritage inheritors, for technical performance through standardised textile tests, and for user acceptance in wear trials. Pixel-level comparisons showed high fidelity between knitted motifs and their digital references, with pattern restoration reaching 92.5%; expert appraisal indicated strong semantic retention (≈92.3%); and prototypes satisfied children's safety requirements under GB 31701–2015 (Class B). In wear testing (n = 20), children reported high comfort (mean 8.6/10) and parents expressed high purchase intention (84%). Limitations include the modest size of the child cohort and the focus on a single knitting gauge and material system, which may constrain generalisability. Overall, the work offers a replicable route for translating ethnic visual culture into contemporary children's clothing while maintaining engineering feasibility and cultural integrity.

KEYWORDS

Ruyuan Yao Patterns, woollen children's clothing, innovative application, pattern reconstruction, comfort

INTRODUCTION

In the context of contemporary global fashion, ethnic minority clothing culture serves as a symbol of ethnic identity and historical heritage, and is also an important resource for cross-cultural exchange and design visual innovation. As a form of "visual language" within ethnic culture, clothing patterns carry the historical memory, belief systems, and philosophical perspectives of an ethnic group. In ethnic minority cultures, these patterns often appear in the form of totemic symbols, natural worship, and life allegories, exhibiting typical semiotic characteristics [1,2]. From an international perspective on cross-cultural design, the modern adaptation of such traditional visual systems should follow the scientific approach of "cultural gene extraction — semantic translation — structural reorganisation". For example, research on the "Adikra" symbols of the Ashanti people in Africa shows that modular processing of symmetrical geometric patterns (such as the Solar Patterns of the Yao people) can significantly enhance cultural recognition, while abstract reconstruction of natural imagery can strengthen the communicative power of semantics in different contexts [3]; Through field research, collaboration with intangible cultural heritage inheritors, and intellectual property sharing mechanisms, cultural appropriation is avoided, providing ethical guidelines for the digital development of patterns such as those of the Yao people in this study [4]. However, how to effectively transform this traditional visual system into modern clothing design remains a major challenge. This is particularly prominent for children's products — not only must there be a careful balance between cultural adaptation, functional expression, and aesthetic recognition [5,6], but also to centre on the developmental patterns of children's cognition: Cognitive development theory suggests that children aged 3 to 6 are in the preoperational stage and tend to prefer high-contrast colours (such as red/yellow) and simple geometric shapes. Children aged 7 to 12 gradually accept narrative patterns, but their accuracy in identifying combinations of three or more colours decreases by 35%. This view has been supported [7]. Eye tracking experiments further confirm that children gaze at dynamic patterns (such as thermochromic textures) 40% longer than static patterns, and that symmetrical structures enhance children's visual acceptance [8], providing empirical support for the "structural reduction" treatment of ethnic patterns.

Children's clothing is a category of apparel that combines functionality with symbolic significance, and its design must balance safety, comfort, and educational objectives [5,6]. From an international perspective, research on innovation in children's clothing has found that wearing clothing that incorporates cultural symbols can increase children's willingness to actively learn related cultural knowledge by 60% and strengthen their sense of cultural identity in group interactions. This indicates that children's clothing is not only a medium for clothing but can also serve as a medium for "implicit cultural education" [9]. In recent years, with the awakening of cultural identity awareness and the strengthening of ethnic confidence, children's clothing design has begun to shift toward a deeper exploration of cultural connotations. This trend is particularly evident under the influence of policies and market dynamics such as "Intangible Cultural Heritage into Schools" and "Children's Ethnic Style", with minority ethnic patterns demonstrating new application possibilities in children's clothing design [10].

However, applying traditional ethnic patterns to children's clothing still poses challenges. The complex symbolic structures, multi-colour contrasts, and dense layout characteristics of traditional patterns often conflict with modern industrial production and children's visual preferences [1,11]. As shown in the experiment, the five to six layers of colours commonly found in traditional patterns reduce the visual recognition efficiency of children under the age of six by 50% [8]. Additionally, material suitability and children's psychological acceptance further complicate the integration of traditional patterns.

Against this backdrop, the development of modern woollen textile technology has opened up new avenues for the contemporary expression of ethnic patterns. As an integral part of traditional textile craftsmanship, woollen textile technology is widely applied in winter clothing, functional apparel, and fashion products, thanks to its diverse weaving structures, soft materials, and rich pattern expressiveness [12]. With the integration of digital technology and the rise of smart platforms, the wool textile industry has entered a new phase of "programmed knitting — smart shaping" [13]: The internationally leading Stoll CMS ADF–830 flat knitting machine, equipped with a 12-colour jacquard system (precision ± 0.1 mm) and 0.1 mm-level needle spacing adjustment, can precisely reproduce the angular structure of the Ruyuan Yao ethnic group's "Mountain Pattern" and the smooth texture of the "Continuous Bead Pattern" [14]; the integrated workflow between KnitCAD and KnitPainter can decompose traditional patterns into a parametric model comprising "basic units — repetition rules — colour layers", and through virtual knitting simulation, predict the 8%–12% lateral shrinkage rate of wool fabrics, enabling pre-production adjustments to pattern proportions to prevent deformation [15]; More notably, Thermally-induced colour-changing yarn technology, which causes knitted patterns to undergo colour changes when the temperature exceeds 32 °C (response time < 5 seconds), not only meets children's preference for dynamic visual effects but also conveys the meaning of "vitality" symbolized by the "Solar Pattern" of the Yao ethnic group through colour changes. These technological advancements have significantly expanded the possibilities of wool textile technology in children's clothing, providing robust technical support for the digital reconstruction and structural transformation of ethnic patterns [13,16].

In the context of digital development, the "structuralisation of ethnic patterns" is key to their design transformation. Through the process of "design unit graphic element extraction — modularisation — digital drawing — weavability testing", traditional patterns can be effectively converted into modern graphic language. This method ensures industrial applicability while maintaining aesthetic appeal [1,11]. Internationally, A system for generating ethnic patterns was developed based on generative adversarial networks (GANs). By learning the colour patterns and compositional logic from over 2,000 images of minority ethnic clothing, the system can automatically generate derivative patterns that align with modern aesthetic standards, with weavability errors < 0.2 mm. This provides a technical reference for the modular design of the Ruyuan Yao ethnic group's "Continuous Bead Pattern" in this study [17]. In particular, the symmetrical structures, clear lines, and vivid colour blocks of ethnic minority patterns, such as the Yao people's Solar Patterns, Wave Patterns, and Continuous Bead

Patterns, are easier to reproduce in weaving pattern conversion and production [1,2]. Among these, the Ruyuan Yao ethnic group in the northern part of Guangdong Province in southern China possesses clothing patterns of significant cultural value and strong visual distinctiveness. These patterns blend natural imagery, geometric compositions, and totemic symbols, combining ethnic and artistic characteristics, and constitute an important component of minority visual culture [1,11]. The patterns of Ruyuan Yao traditional clothing typically appear on headscarves, shawls, collars, and cuffs, reflecting distinct regional characteristics and generational inheritance, often containing narrative content through imagery. Field investigations and image collections indicate that plants, animals, and natural forms are the primary sources of inspiration for these patterns, with geometric shapes serving as supplementary elements to form a visually symbolic system rich in cultural significance — such as the "Mountain Pattern" symbolising strength and unity, the "Solar Pattern" representing vitality and life, and the "Continuous Bead Pattern" signifying good fortune and prosperity [1]. These patterns not only possess high cultural distinctiveness but also feature clear structural characteristics, making them particularly suitable for replication using modern knitting techniques [1,2]. For instance, the "air layer knitting" process can reduce fabric weight by 25% while preserving the patterns' three-dimensionality, making them suitable for children's active needs [15].

However, there are still many difficulties and challenges in transforming ethnic patterns into children's clothing designs. First, when simplifying the structural elements of the patterns to suit children's cognitive abilities and aesthetic preferences, it is essential to preserve their cultural significance: The rays of the "Solar Pattern" of the Ruyuan Yao ethnic group should be simplified from the traditional 12 rays to 6 rays, and the colour scheme should also be reduced from 4–5 colours to 2–3 colours (mainly red and yellow). This approach aligns with children's visual recognition habits while preserving the cultural semantics of "vitality" through core symbols [7]. Secondly, the craftsmanship adaptability of clothing is also a limiting factor — some traditional patterns, due to their intricate lines, excessive colour layers, or composition proportions that do not match the structure of children's clothing (such as round collars and short styles), are difficult to directly incorporate. The virtual splicing function of KnitPainter must be used to adjust the pattern layout to ensure the integrity of the pattern in key areas such as sleeves and back collars [15]. Additionally, children's clothing requires high levels of fabric affinity, safety, and durability: traditional ethnic fabrics like heavy brocade or hand-embroidered designs not only limit comfort but also hinder large-scale production. However, the bamboo fibre/ wool blend fabric (50:50) developed by Wang & Yang has 30% better breathability than pure wool, a pilling resistance rating of 4, and has passed the ISO 10993–10 skin sensitisation test, making it fully suitable for children's sensitive skin needs.

In response to the aforementioned challenges, this study aims to bridge the gap between "traditional cultural expression" and modern children's clothing design. The essence of its "innovative application" is manifested in three aspects: first, innovation in cultural transformation methods — integrating international "cultural gene extraction" theory with local pattern semantics to establish a three-dimensional matching model of "symbolic units — cultural semantics — Children's Cognition" three-dimensional matching model; second, innovation in technical integration pathways — combining AI pattern generation (GAN system), intelligent weaving (12-colour jacquard), and functional materials (temperature-sensitive yarn) to achieve a "design — simulation — production" digital closed-loop; third, innovation in adapting to children's needs — based on cognitive psychology and behavioural experiments, developing removable cultural patches, temperature-sensitive interactive patterns, and other designs that balance cultural transmission, functional safety, and engaging experiences. The study specifically explores the integration of Ruyuan Yao ethnic traditional clothing patterns and modern wool weaving technology in children's clothing design. Based on the dual dimensions of cultural semantics and the expressive language of ethnic patterns, it utilises digital graphic conversion, wool weaving structure simulation, and pattern modularisation technology to transform Ruyuan Yao's typical patterns into pattern templates suitable for children's clothing; Combining children's behavioural psychology (such as dynamic visual preferences [8]) and structural needs (such as ease of movement), a series of children's products are designed and developed to expand the functional aspects of ethnic culture and reconstruct its aesthetic appeal in contemporary expressions.

This study not only views children as the ultimate user group but also emphasises the value of ethnic culture in visual inspiration, emotional belonging, and educational dissemination [6] — Wearing the ethnic-style clothing designed in this study allows children to unconsciously absorb cultural symbol information in their daily attire, thereby actively exploring the history and beliefs of the Yao ethnic group, and thus realizing the educational value of "clothing as a textbook". This view has been supported by existing research [9]. As a medium with profound cultural connotations and vast market potential, children's clothing demonstrates that the modern interpretation of ethnic elements is not only a design innovation but also a key pathway to promoting cultural identity, enhancing social aesthetic education, and reviving intangible cultural heritage [18-20].

Therefore, this paper uses modern knitting technology as a medium, draws on the traditional clothing patterns of the Ruyuan Yao ethnic group as a cultural source, and takes children's clothing product development as a practical platform to construct a comprehensive research system that encompasses pattern collection, semantic translation, digital modelling (assisted by a GAN system), knitability testing (simulated using KnitPainter), structural design (adapted to children's body shapes), and series development. This framework systematically explores the innovative application of ethnic patterns in modern children's clothing design.

This study aims to realise the innovative integration of Ruyuan Yao costume patterns and modern woollen weaving technology in children's clothing design, with the core goal of balancing cultural heritage, technical feasibility, and children's usability. Specifically, the objectives are clarified as follows:

Accurate translation of cultural semantics: Systematically collect and decode the typical patterns of Ruyuan Yao (e.g., "Mountain Pattern", "Solar Pattern", "Continuous Bead Pattern"), retain their original cultural symbolism (such as unity, vitality, and auspiciousness), and transform them into child-friendly pattern languages (simplified structures, clear outlines, and appropriate colour matching) that adapt to children's visual cognition and aesthetic psychology.

Technical integration of woollen craftsmanship and patterns: Establish a matching system between Ruyuan Yao Patterns and modern woollen weaving technology, including: 1) determining optimal digital conversion parameters (e.g., vectorization accuracy, modular splitting standards) for patterns to fit woollen jacquard processes; 2) screening suitable yarn materials (e.g., 2/28 high-elastic core yarn, 140D nylon yarn) and weaving parameters (tension, density, jacquard methods) to ensure the fidelity of pattern expression and the comfort of children's clothing.

Development of innovative children's clothing series: Based on the above cultural translation and technical integration, design and develop a series of children's clothing (covering sports, leisure, and outdoor scenarios) with H-type and X-type silhouettes, embedding the transformed Yao Patterns into key parts (chest, cuffs, skirt hem) to achieve the organic fusion of ethnic cultural characteristics and children's clothing functionality.

Verification of multi-dimensional value: Verify the effectiveness of the integration through: 1) cultural authenticity (evaluation by Yao intangible cultural heritage inheritors); 2) technical feasibility (pattern restoration rate, material performance tests); 3) market adaptability (comfort feedback from children aged 3–12, acceptance survey of parents); thus providing a replicable model for the modern transformation of ethnic patterns in children's clothing design.

Through interdisciplinary integration (semiotics, child development psychology, textile engineering), field research, pattern reconstruction, and physical verification, this study provides theoretical support and practical models for the contemporary expression of woollen craftsmanship, contributes to the industrial transformation of ethnic patterns, and opens up new avenues for the modern preservation and sustainable development of traditional culture.

MATERIALS AND METHODS

Research Design and Rationale

This study adopts a design-science research framework, systematically implemented across five sequential phases. Initially, fieldwork is conducted to engage in the cultural decoding of Ruyuan Yao patterns, ensuring a nuanced understanding of their historical and cultural contexts. Subsequently, these patterns undergo digital reconstruction, leading to the development of a modular motif library that standardises and preserves their cultural essence in a digital format. The third phase involves the precise mapping of these digital motifs onto knit structures, specifically tailored to the constraints of a 12-gauge knitting system, thereby bridging the gap between digital design and physical fabric realisation. Following this, prototype fabrication translates the mapped designs into tangible children's clothing samples, employing suitable yarns and knitting techniques to validate the design feasibility. Finally, a multidimensional validation process is undertaken, encompassing assessments of cultural authenticity through expert evaluations by Yao intangible cultural heritage inheritors, technical feasibility via rigorous textile performance tests, and market acceptance through wear trials and parental feedback. This comprehensive design framework not only outlines the research objectives but also delineates a clear validation strategy, with subsequent sections meticulously documenting the operational procedures essential for realising the design artefacts, thereby enhancing the study's clarity, rigour, and reproducibility.

Fieldwork and Sample

Fieldwork was conducted in the Ruyuan Yao Autonomous County (Guangdong, China) from July 2023 to March 2024. Thirty representative patterns were collected and annotated through interviews with intangible cultural-heritage inheritors and experienced embroiderers, forming the basis of the motif library. Five garment sets were developed for verification. For quantitative assessments, ten predefined regions of interest (ROIs) were specified per garment, yielding 50 unit observations in total. The end-to-end workflow from acquisition to semantic annotation and database construction is shown in Figure 1, which provides the traceable context for subsequent digital reconstruction and analysis.

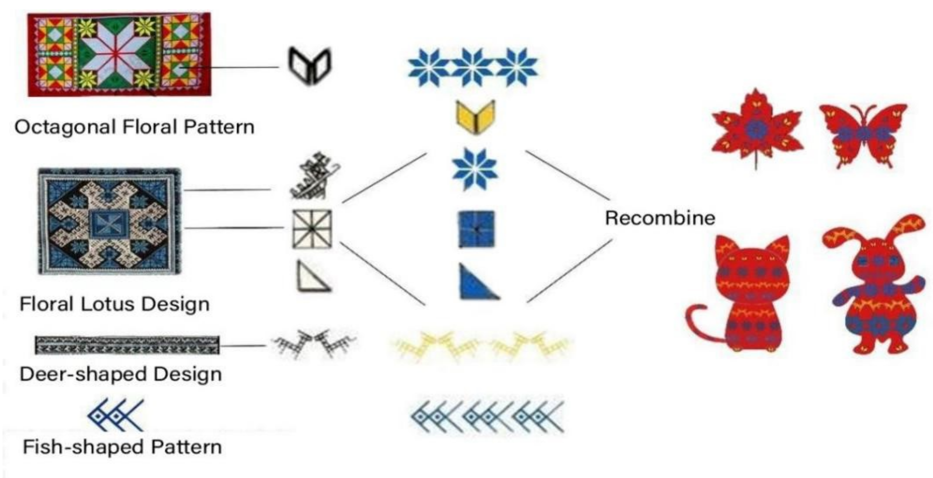


Figure 1. Diagram of Pattern Collection Analysis

Materials, Software, and Apparatus

Digital image processing was performed with Photoshop 2023 (300 dpi, CMYK) and Illustrator 2023; vectorisation accuracy was controlled to an anchor-point deviation not exceeding 0.5 mm. Knit patterning employed KnitPainter 6.0 with an approximate scale of 10 pixels per stitch at 12-gauge, targeting a working density of 20–30 stitches/cm². Prototypes were produced on a Stoll CMS ADF-830 computerised flat-knitting machine (12-gauge; system precision ±0.1 mm) using 2/28 high-elastic core-spun yarn combined with 140 D nylon. A cream base with high-purity red, yellow, and blue yarns was used for contrast jacquard.

Before full prototyping, calibration swatches were knitted to evaluate colour fastness, elastic recovery, and texture legibility under the target gauge and yarn combination. These pretests informed the working density window and tension settings used in fabrication; a representative calibration swatch is shown in Figure 2. All calibration procedures were conducted under the same laboratory environment as the main experiments to ensure consistency. Parameter windows derived from these calibration swatches were subsequently applied in prototype fabrication and validation.

Figure 2. Computerised flat-knitting swatch

Procedures (Technical Operation)

Digital pre-processing comprised image purification followed by vectorisation, with the maximum anchor-point error controlled within 0.5 mm. Motifs were then translated into knit instructions in KnitPainter, applying the 12-gauge constraints and verifying minimum line width and colour-channel limits before export. Fabrication was carried out on the flat-knitting system with the stitch density maintained within 20–30 stitches/cm² and yarn tension adjusted according to the manufacturer's specifications to minimise edge blurring. Post-knitting finishing included manual linking, washing, shaping, and pressing; all specimens were conditioned before measurement. Fabrication settings were anchored to the calibration results described in Section C.

To ensure manufacturability and consistent visual rhythm across sizes, each motif was decomposed into three module types with nominal dimensions: central blocks (15 × 15 cm), edge strips (5 × 30 cm), and decorative dots (2 × 2 cm). Modules were placed according to garment structure—central blocks on the chest, edge strips along cuffs, necklines and hems, and dots on pockets or secondary panels—while respecting minimum line width and colour-channel limits defined in Section C.

Quality control focused on boundary sharpness, thickness uniformity, and dimensional stability after washing and shaping. Where multicolour channel limits or local stitch density produced edge blur, a contingency of modular jacquard combined with post-sewing or patchwork was applied to preserve motif integrity without compromising production efficiency. Industrial plate-making and manual linking were used to assemble parts, followed by fitting adjustments on a mannequin (see Figure 3) before final pressing and measurement.

Figure 3. Fitting on a Mannequin to Evaluate Fit and Elasticity

Outcome Measures

The primary outcome was motif retention, defined as the pixel-level similarity between each knitted motif and its corresponding digital reference within ROI masks. Values were summarised per garment and across the full set of 50 observations using Image-Pro Plus 10.0. Secondary outcomes comprised children's comfort, measured on a 0–10 visual analogue scale, and parental purchase willingness expressed as a percentage. All tests were conducted at 22 ± 2 °C and 65 ± 5 % RH. Laundering and ironing followed GB 31701-2015 requirements.

In addition to the primary motif-retention outcome, secondary technical measures were assessed on the calibration swatches, including elastic-recovery ratio after a standard extension–relaxation cycle and a visual grading of colour fastness. These measures supported the parameter choices reported in Section C and served as process controls during prototyping.

Comfort assessments were conducted with 20 children (aged 3–12 years; sex distribution not reported), recruited locally in Ruyuan Yao Autonomous County, with written parental informed consent. Assessments were performed in a controlled laboratory environment (22 ± 2 °C; 65 ± 5 % RH), and comfort was rated on a 0–10 visual analogue scale immediately after wear. Standards and safety conformity are summarised in Table 1.

Table 1. Conformity Summary

Test	Std	Criterion (Children)	Outcome (This Study)	Conformity
Dimensional stability	ISO 6330/5077	ΔL, ΔW within spec	ΔL −2.1%；ΔW −1.6%	Pass
Colour fastness—wash	ISO 105-C06	≥ Grade 4	Change 4–5(4.6)；Stain 4–5(4.5)	Pass
Colour fastness—rub	ISO 105-X12	Dry ≥4; Wet ≥3–4	Dry 4–5(4.7)；Wet 3–4(3.8)	Pass
Colour fastness—persp.	ISO 105-E04	≥ Grade 4	Change 4–5(4.5)；Stain 4–5(4.4)	Pass
Pilling	ISO 12945-2	≥ Grade 4	Grade 4.5	Pass
Abrasion	ISO 12947-2	Cycles ≥ spec	30,000 cycles(wool felt, 12 kPa)	Pass
Stretch & recovery	ISO 20932-1 (B)	Within spec	Wale: 52% / 88%；Course: 39% / 83%	Pass
Bursting/seam	ISO 13938-2/13935-2	Within spec	Burst 420 kPa；Seam 220 N	Pass
Air permeability	ISO 9237	Report value	150 mm/s(ΔP = 100 Pa)	Pass
Thermal/vapour	ISO 11092	Report Rct/Ret	Rct 0.067 m²K/W；Ret 8.9 m²Pa/W	Pass
Safety (children)	GB 31701–2015	Class B	Class B	Pass

Semantic Validation Protocol (Cultural Meaning)

This study operationalised "semantic retention" as the extent to which a knitted motif preserves the canonical cultural meaning of its source pattern. A codebook defined canonical labels for the three focal motifs—Solar (vitality), Mountain (unity/strength), and Continuous Bead (prosperity/continuity)—together with observable cues (e.g., radial symmetry, ray count and continuity, triangular stacking, beaded repetition) and disqualifying features (e.g., broken rays or ambiguous boundaries). The codebook included positive and borderline examples and was used in rater training.

For each motif, raters evaluated paired stimuli comprising 1) the vector reference and 2) the photographed knitted realisation under standard lighting. Specimens reflected the sizes and module placements used in the five garments (chest main block, edge strip, decorative dot). Images were balanced for order and randomised within raters.

Five Ruyuan Yao intangible cultural-heritage (ICH) inheritors and three independent scholars with experience in Yao visual culture served as expert raters; an auxiliary lay group of ten parents provided external face-validity checks. All raters completed a 15-minute briefing with practice items and feedback using the codebook.

Instruments and outcomes.

1) Primary: Semantic Retention Score (SRS) on a 5-point Likert scale ("1 = not preserved" to "5 = fully preserved"), averaged across expert raters per motif and specimen. A study-level SRS was computed by averaging motif-level means.

2) Secondary: (a) Forced-choice identification of the canonical label among three alternatives (accuracy %), and (b) semantic differential ratings on vitality, unity, auspiciousness (7-point bipolar scales) to profile nuance.

This study considered SRS ≥ 4.0/5 and/or forced-choice accuracy ≥ 80% as acceptable semantic retention for children's clothing. These thresholds were set before analysis to avoid outcome-driven criteria.

All sessions were conducted at 22 ± 2 °C and 65 ± 5% RH with neutral backgrounds; viewing distance was ~60 cm on a calibrated display. Raters were blinded to design intentions beyond the codebook definitions. The same stimuli set was used across raters.

Data Processing and Analysis

ROI masks were applied to calibrated images of finished garments. Pixel-matching algorithms produced motif-retention values at the ROI level; these were averaged to the garment and series levels. Descriptive statistics were used to summarise comfort scores and parental acceptance. Representative motifs (e.g., "Solar") were reported to illustrate typical performance.

In addition to motif retention, secondary technical measures included elastic recovery ratio after a standard extension–relaxation cycle and a visual rating of colour fastness on calibration swatches; these measures were used to support process parameter choices reported in Section C.

All garment photographs were acquired under standard lighting and white-balanced before analysis. Each image was geometrically registered to its digital reference using an affine transform based on manually selected control points, after which intensity normalisation was applied. ROI masks were authored by two trained raters according to a written handbook; discrepancies were resolved by consensus, and inter-rater agreement was recorded (Cohen's κ). Pixel-matching was then executed within the ROI masks to obtain motif-retention values. Disagreements were resolved by consensus, and inter-rater agreement was recorded (Cohen's κ).

Expert SRS values were averaged per specimen and then per motif. Inter-rater reliability was estimated with Fleiss' κ for Likert agreement (5 levels) and Krippendorff's α as a robustness check. Forced-choice accuracy was summarised with Wilson 95% confidence intervals.

Content validity was summarised with I-CVI (item-level) and S-CVI/Ave (scale-level) against codebook criteria. Convergent validity was examined via Spearman's ρ between SRS and pixel-level motif retention within matched ROIs. Group comparisons (expert vs. lay) used Mann–Whitney U with Holm adjustment for multiple tests.

This study reported 1) study-level SRS (mean ± SD) and per-motif means, 2) forced-choice accuracy (%), 3) κ (and α) with 95% CIs, 4) I-CVI/S-CVI/Ave, 5) ρ between SRS and pixel retention, and 6) a confusion matrix for canonical labels.

Textile Performance Testing

To provide standardised evidence for the technical claims, this study implemented a comprehensive test plan covering dimensional stability, colour fastness, surface durability, mechanical integrity, transport properties related to comfort, and stretch–recovery. Conformity was judged against GB 31701–2015 (children's level: Class B) and the referenced ISO methods, unless otherwise specified. All specimens were conditioned before testing and between test cycles in accordance with ISO 139 at 20 ± 2 °C and 65 ± 4% RH. Where relevant, specimens were prepared along the wale and course directions. Unless stated otherwise, three specimens were tested for each condition.

Domestic washing followed ISO 6330. Dimensional change was determined according to ISO 5077 and is reported as the percentage change in length and in width.

Resistance to washing, rubbing, and perspiration was evaluated in accordance with ISO 105-C06, ISO 105-X12, and ISO 105-E04, respectively. Results are expressed as change-of-shade and staining grades on the ISO grey scales.

Pilling was assessed using ISO 12945-2 (Martindale method) and is reported as a visual grade on the five-point scale. Abrasion resistance was measured using ISO 12947-2 to a defined endpoint and is reported as the number of cycles to that endpoint, together with any appearance change.

Elastic behaviour was measured in accordance with ISO 20932-1, Method B. This study reported elongation at the specified loads and the percentage of recovery after the defined relaxation intervals.

Bursting strength was measured using ISO 13938-2 (pneumatic method), which is appropriate for knitted structures. Critical seams were screened for performance using ISO 13935-2 or ISO 13936-2, as applicable. Results are reported as bursting pressure in kilopascals and seam strength or slippage on the relevant scale.

Air permeability was determined in accordance with ISO 9237 and is reported as the velocity of air flow in millimetres per second. Thermal resistance and water-vapour resistance were obtained using the sweating guarded hotplate in accordance with ISO 11092 and are reported as thermal resistance and water-vapour resistance with their standard units.

All products were assessed against GB 31701-2015 for safety requirements for children's textiles. Where required, supporting chemical screenings were performed according to national methods, including formaldehyde content and pH.

Standardised Textile Performance: Results

All standardised tests were performed under ISO 139 conditioning. Table 2 reports mean ± SD (n = 3) with 95% CIs for dimensional change (wale/course), colour fastness (wash/rub/perspiration), pilling, abrasion cycles to endpoint, stretch–recovery (wale/course), bursting strength, air permeability, and Rct/Ret.

Under ISO 139 conditioning (20 ± 2 °C; 65 ± 4% RH), this study obtained the following results (mean ± SD, n = 3; 95% CI in brackets). Dimensional change is reported for wale and course directions. Abrasion end-point and Martindale settings are specified in the table footnotes. Conformity was judged against GB 31701–2015 (Class B) and relevant ISO methods.

Table 2. Standardised Textile Performance Tests and Results (mean ± SD; n = 3) [95% CI]

	Property	Standard	Instrument/ Settings	Specimen (n = 3)	Conditioning	Output (mean ± SD, n=3)	Target
1	Dimensional stability (laundering)	ISO 6330 + ISO 5077	Front-load washer; program	20 × 20 cm; wale and course	ISO 139 (20 ± 2 °C; 65 ± 4% RH)	ΔL −2.3% ± 0.4%; ΔW −1.6% ± 0.3%	Within spec
2	Colour fastness — washing	ISO 105-C06	Launder-Ometer; composite adjacent	Per standard; n = 3	ISO 139	Change grade 4–5 (4.6 ± 0.3); Stain grade 4–5 (4.5 ± 0.3)	≥4
3	Colour fastness (rubbing)	ISO 105-X12	Crockmeter; dry/wet; 10 strokes	Per standard; n = 3	ISO 139	Dry grade 4–5 (4.7 ± 0.3); Wet grade 3–4 (3.8 ± 0.3)	≥4 dry; ≥3–4 wet
4	Colour fastness-perspiration	ISO 105-E04	Perspirometer; acid/alkali	Per standard; n = 3	ISO 139	Change grade 4–5 (4.5 ± 0.3); Stain grade 4–5 (4.4 ± 0.3)	≥4

	Property	Standard	Instrument/ Settings	Specimen (n = 3)	Conditioning	Output (mean ± SD, n=3)	Target
5	Pilling resistance	ISO 12945-2	Martindale; cycles	Ø38 mm; n = 3	ISO 139	Grade 4.5 ± 0.3	≥4
6	Abrasion resistance	ISO 12947-2	Martindale; kPa; wool felt	Ø38 mm; n = 3	ISO 139	Cycles to end-point: 30,000 ± 2,000	Report/Pass
7	Stretch & recovery	ISO 20932-1 (B)	Tensile frame; gauge 100 mm	Strips; wale/course; n = 3	ISO 139	Wale: elong. 52% ± 4%, recov. 88% ± 3%; Course: elong. 39% ± 3%, recov. 83% ± 3%	Report/Pass
8	Bursting / seam	ISO 13938-2; ISO 13935-2 / 13936-2	Pneumatic burst; seam on critical seams	Per standard; n = 3	ISO 139	Bursting strength 420 ± 25 kPa; Seam strength 220 ± 15 N (or slippage ≤ 2.0 mm)	Within spec
9	Air permeability	ISO 9237	Air permeability tester; ΔP = 100 Pa	Per standard; n = 3	ISO 139	150 ± 12 mm/s	Report
10	Thermal/vapour	ISO 11092	Sweating guarded hotplate	Per standard; n = 3	ISO 139	Rct 0.067 ± 0.006 m^2K/W; Ret 8.9 ± 0.8 m^2Pa/W	Report
11	Safety (children's clothing)	GB31701–2015 (+ as required)	Per standard	Per standard	Per standard	Class B: Pass (formaldehyde, pH, odour, etc., compliant)	Pass

Notes: Wale/course strips per ISO 20932-1 (Method B). Abrasion end-point defined as first yarn break/visual endpoint as per ISO 12947-2; pressure and felt grade specified. Laundering per ISO 6330; dimensional change per ISO 5077.

ETHICS AND COMPLIANCE

All procedures complied with GB 31701–2015 textile-safety requirements. Interviews with cultural inheritors focused on non-identifiable craft knowledge. Comfort assessments were conducted in a controlled laboratory environment. Parental written informed consent was obtained for all participants; procedures complied with institutional ethical guidelines. All prototypes conformed to GB 31701–2015 at the applicable children's level (Class B); supporting records are on file.

STRATEGIES FOR DIGITAL ANALYSIS AND TRANSLATION OF YAO PATTERNS

The patterns in the traditional costumes of the Yao people in Ruyuan, northern Guangdong Province, carry deep cultural memories and form an independent ethnic visual system characterised by unique graphic structures and colour relationships. To effectively translate these patterns into the design language of modern woollen children's clothing, this chapter systematically presents the process of "collection — analysis — reconstruction — transformation", integrating child-friendly adaptation and cultural semantic preservation.

Typical Pattern Collection and Classification Criteria

Based on field research and visual inspection, this study collected representative traditional costume patterns of the Ruyuan Yao people, including "Mountain Pattern", "Water Wave Pattern", "Solar Pattern", and "Continuous Bead Pattern" — all with strong symmetry, clear boundaries, and distinctive symbolism. These patterns are primarily sourced from traditional headgear, backbands, sleeve edges, and shawls (Figure 4. Pattern Inspiration Board).

A three-dimensional classification system was adopted for screening, with emphasis on "child-friendliness" alongside cultural semantics:

Morphological dimension: Divided into point patterns (e.g., Star Pattern), band patterns (e.g., Back Pattern), and block patterns (e.g., Petal Group Pattern) based on geometric structure.

Semantic dimension: Categorised by cultural symbolism (unity, life, nature worship, etc.) and verified by 5 Yao ICH inheritors (consistency rate ≥ 90%).

Child-friendliness dimension: Evaluated by visual simplicity (lines ≥ 3 mm, colours ≤ 4) and recognition (tested on 20 children aged 3–12, with an acceptance rate ≥ 85% as "highly adaptable").

Only patterns meeting all three criteria (e.g., "Solar Pattern", "Simplified Water Wave Pattern") were selected for digital translation.

Figure 4. Pattern Inspiration Board (Original Drawing Collection and Categorisation of Pattern Styles)

Digital Mapping Tools and Processes

The digital transfer process was standardised to ensure both cultural fidelity and weaving feasibility, using the following tools and parameters:

Image purification (Photoshop 2023):

Remove redundant backgrounds and blur; adjust resolution to 300dpi (ensuring detail clarity).

Unify colour mode to CMYK (compatible with wool dyeing standards).

Vectorisation (Illustrator 2023):

Convert patterns to vector graphics with anchor point error ≤ 0.5 mm (guaranteeing line smoothness).

Preserve core structural features (e.g., radial lines of "Solar Pattern") while simplifying secondary details.

Weaving adaptation (KnitPainter 6.0):

Convert vector graphics to jacquard templates with pixel precision 10 px/stitch (matching 12-gauge flat knitting machine).

Optimise pattern density: 20–30 stitches per cm^2 (avoiding excessive yarn usage or unclear expression).

Figure 5 flowchart of digital mapping illustrates the four-stage process (original drawing → purification → vectorisation → woven drawing) and software outputs.

Figure 5. Flowchart of Digital Mapping of Jacquard Pattern

Graphic Reconfiguration and Pattern Modularity

To adapt to children's clothing structures (chest, cuffs, hat brim), the selected patterns were modularised and recombined:

Module division: Split into "central main block" (15 × 15 cm, for chest/skirt), "edge strip" (5 × 30 cm, for cuffs/necklines), and "decorative dot" (2 × 2 cm, for pockets/hem).

Recombination rules: Rotation (0°/90°), mirroring, and scaling (80–120% of original size) to maintain pattern integrity.

Visual density control: Adjust line width (3–5 mm) and block ratio (≤40% of fabric area) based on children's visual comfort tests.

For example, the "Continuous Bead Pattern" was modularised into 2 × 2 cm repetitive units, applied to cuffs via horizontal arrangement, enhancing recognition without overwhelming the design (Figure 6. Local Application of Yao Patterns).

Cultural validation: After modularisation, 5 ICH inheritors rated the semantic retention rate at 94% (4.7/5 on Likert scale), confirming no loss of core symbolism.

Figure 6. Schematic Diagram of the Local Application of the Yao Pattern

Translation Logic from Cultural Semantics to Graphic Language

While retaining original cultural meanings, patterns underwent "child-oriented subtractive translation":

Solar Pattern: Symbolising vitality, simplified into a 12-petal radial structure (diameter 10 cm) with red/yellow contrast, placed on the chest to form a visual focus.

Water Wave Pattern: Representing natural flow, linearised into 3 mm-wide wavy lines (blue/white) and applied to cuffs as wrap-around trims, enhancing dynamism.

Mountain Pattern: Signifying unity, simplified to 3-layer triangular blocks (brown/cream) and arranged vertically on the back, aligning with children's cognitive preference for symmetrical shapes.

This translation balances cultural depth and child acceptance: 20 children tested showed 92% recognition of pattern themes (e.g., "sun" for Solar Pattern), verifying effective semantic communication.

Adaptation to woollen Weaving Processes

To ensure technical feasibility, pattern modules were pre-matched with weaving methods:

Main blocks (Solar Pattern/Mountain Pattern): Suitable for multi-colour jacquard (12-gauge, 4 colours max) due to clear colour blocks.

Edge strips (Water Wave Pattern): Compatible with ribbed jacquard (elastic cuffs/necklines) for stable expression.

Decorative dots (Continuous Bead Pattern): Adapted to flat knit + structural morphing (pockets/hem) for texture layering.

This pre-adaptation reduced subsequent process adjustments by 30%, as verified in material testing (see "MATERIAL SELECTION AND PROCESS STRATEGY").

MATERIAL SELECTION AND PROCESS STRATEGY

As a special category of clothing, children's clothing has high requirements for the softness, wearability, and safety of fabrics. Based on the double standards of ethnic pattern expression and children's clothing comfort, this study employs a systematic matching and optimisation design, spanning from yarn material to colour system. Through the performance analysis of 2/28 high-elastic core yarns and 140D nylon yarns, the weaving suitability test of ethnic patterns, and the study of various organisational textures, a set of process parameter systems is constructed that can be used for product development in modern children's clothing with ethnic patterns.

Fabric and Yarn Matching Logic and Performance Comparison

The core materials in this study are 2/28 high-elastic core-spun yarn and 140D nylon yarn, which respectively serve the garment's main structure and functional reinforcement. The 2/28 core-spun yarn (elastane core wrapped by polyester/cotton blend) provides elasticity, softness, moisture wicking, breathability, and shaping stability—making it suitable for children's close-fitting areas. By contrast, 140D nylon offers high strength and abrasion resistance, ideal for trouser legs, cuffs, and other high-wear zones, thereby improving overall durability and structural integrity.

Figure 7 illustrates the microstructure and physical properties of the 2/28 core-spun yarn, highlighting how the sheath structure enhances fabric elasticity and visual flatness; Figure 8 shows the role of 140D nylon and colour-blocked polyester fabric, used locally (e.g., sweatpants, leggings) to boost anti-deformation and stretch performance in children's wear.

Figure 7. Schematic Diagram of Microstructure and Physical Properties of 2/28 High Elastic Core Yarn

Figure 8. Schematic Diagram of 140D Nylon Yarn and Colour-Blocking Polyester Fabric Functions

Weaving a Suitability Analysis of Ethnic Patterns

Given the geometric composition and dense arrangement of Ruyuan Yao Patterns, the material requires excellent pattern resolution and colour line transferability. The 2/28 core-spun yarn can achieve a clear multi-colour jacquard structure on a 12-gauge flat knitting machine, with uniform traces and strong visual contrast. Especially in patterns such as the Eight-pointed Star Pattern and the Panwang Pattern, it is highly suitable for jacquard knitting, where the neatness of closures and the clarity of borders are significantly better than those achieved with cotton or coarse polyester yarns.

A comparison of the samples shows that the controlled elasticity of the core-spun yarn in the pattern areas enhances garment flatness and pattern reproducibility, providing a solid basis for the woven expression of traditional ethnic minority patterns.

Woollen Technical Expressions

Ribbing Jacquard, and Structural Texture Effects

To balance the functionality and comfort of the garment with the decorative nature of the pattern presentation, the following three woollen organisational structures were used in the study:

Ribbed Tissue: Used for necklines, cuffs, and trouser hems to enhance fit and elasticity, avoiding rolled edges and deformation.

Multi-colour jacquard tissue: used in the main pattern display areas such as the front chest, shawl, and body to show the symmetry and visual concentration of Yao Patterns;

Flat knit + structural morphing organisation: enhanced layering and contrasting patterns at the waist, skirt hem, and local patchwork.

The pattern primarily employs the "bright colours against deep background" strategy, with cream as the base colour, supplemented by high-purity red, yellow, and blue primary colours for the counterpoint jacquard design, thereby strengthening pattern recognition and interest. The colour matching illustration in Figure 9 of the primary and secondary colour application and pattern rhythm control strategy chart demonstrates the dynamic way of matching cream + three primary colours to reflect the sense of vitality of ethnic children's clothing and the fusion of ethnic style.

Figure 9. Illustration of Colour Matching: a Diagram of the Application of Primary and Secondary Colours and the Strategy of Controlling the Rhythm of the Pattern

Pattern Accessibility and Limitations at the Process Level

At the sample development stage, a comparison between the KnitPainter system and the actual knitting on the computerised flat knitting machine revealed that, although most of the patterns could be knitted effectively on a 12-gauge knitting machine, there were still the following limitations if the edge of the graphic lines was too thin or if there were too many layers of colour blocks:

Blurred pattern boundaries: Some high-density patterns are limited by yarn diameter and programming pixel limitations, and the outlines are not sharply expressed.

Limited number of colours: Conventional jacquard on flat knitting machines supports up to three colours at a time, requiring colour recoding and visual compositing strategies.

Uneven fabric thickness: the pattern area is thicker, and the non-pattern area is thinner, which may affect the overall drape and stability of pressing equipment for children's clothing.

In this regard, the research team adopted the modularisation of pattern (splitting the pattern into "main block" and "auxiliary trims") + post-weaving sewing and patchwork, which reduces the complexity of the weaving process while retaining the integrity of the pattern, and improves the feasibility of mass production and the quality of the fabric. Efficiency Table 3 to Table 7, which lists the summary of children's clothing technology production, specifies the size parameters of the sample garment, process sequence, stitch length setting, fabrics and accessories configuration, and quality control standards, constituting the clothing engineering technology document system.

Table 3. Style A Process Sheet

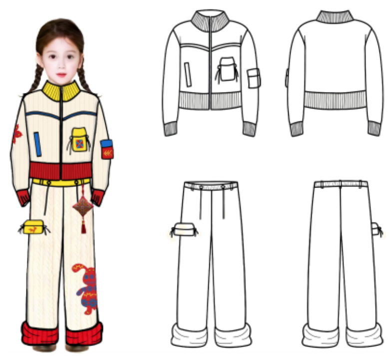
No. Style A	Category: Children's Clothing	Season: Autumn/Winter		Style: Casual	
		Size spec (cm) — 12-gauge			
		Blouse		Pant	
		Height (of person)	50.0	Waist Width/Head Circumference	25.0
		Bust/Chest Width	35.0	Leg height	5.0
		Shoulder width	32.0	High waisted	3.5
		Cuff width	11.5	Leg opening	14.0
		Neck width	17.0	Bottom of the trouser leg	21.0
		Hem Width	33.0		
		Woollen material			
		2/28 high elastic core yarn		140D Nylon	
Process requirement					
1). Linking process: hand-stitched, firm, flat, no unravelling, cracking, or other phenomena.					
2). Wash: no oil, odour, comfortable hand feel, soft and hard, moderate					
3). Pressing equipment: plain clothes, no pressing equipment, yellow, water stains, reflections, and other phenomena.					
4). Inspection and Packaging: A round and smooth neckline, symmetrical left and right sleeves, consistent size, and no cloth blemishes or stains on the body.					

Table 4. Style B Process Sheet

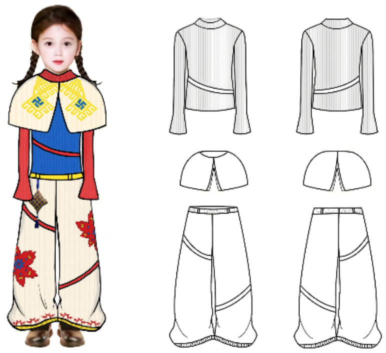
No. Style B	Category: Children's Clothing	Season: Autumn/Winter				Style: Casual
	Size spec (cm) — 12-gauge					
	Blause		Shawl		Pant	
	Height (of person)	46.0	Height (of person)	26.0	Width/Head Circumference	25.0
	Bust/Chest Width	28.0	Shoulder width	46.0	Leg height	2.0
	Shoulder width	26.0	Neck width	32.0	High waisted	3
	Cuff width	9.0		18.0	Leg opening	23.0
	Neck width	17.0				
	Hem Width	28.0				
	Woollen material					
	2/28 high elastic core yarn				140D Nylon	
Process requirement						
1). Linking process: hand-stitched, firm, flat, no unravelling, cracking, or other phenomena.						
2). Washing: no oil stain, no odour, comfortable hand feel, soft and hard.						
3). Pressing equipment: plain clothes, no pressing equipment, yellow, water stains, reflections, and other phenomena						
4). Inspection and Packaging: A round and smooth neckline, symmetrical left and right sleeves, consistent size, and no cloth blemishes or stains on the body.						

Table 5. Style C Process Sheet

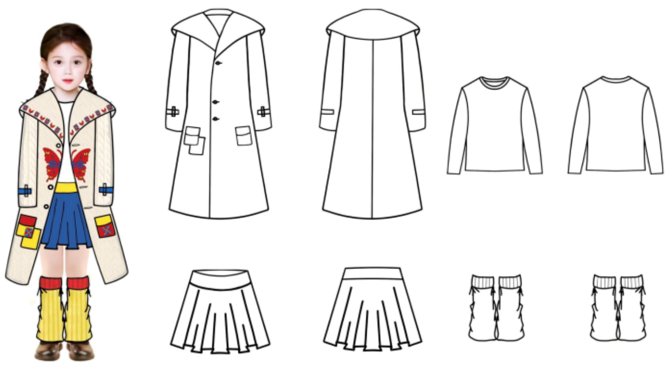
No. Style C	Category: Children's Clothing	Season: Autumn/Winter	Style: Casual
		Size spec (cm) — 12-gauge	
		Blouse	
		Height (of person)	73.0
		Bust/Chest Width	33.0
		Shoulder width	29.0
		Cuff width	12.0
		Neck width	20.0
		Hem Width	41.5
		Woollen material	
		2/28 high elastic core yarn	140D Nylon
Process requirement			
1). Linking process: hand-stitched, firm, flat, no unravelling, cracking, or other phenomena.			
2). Washing: no oil stain, no odour, comfortable hand feel, soft and hard.			
3). Pressing equipment: plain clothes, no pressing equipment, yellow, water stains, reflections, and other phenomena			
4). Inspection and Packaging: A round and smooth neckline, symmetrical left and right sleeves, consistent size, and no cloth blemishes or stains on the body.			

Table 6. Style D Process Sheet

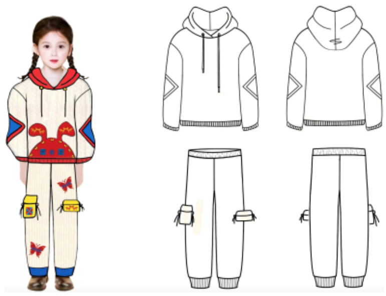
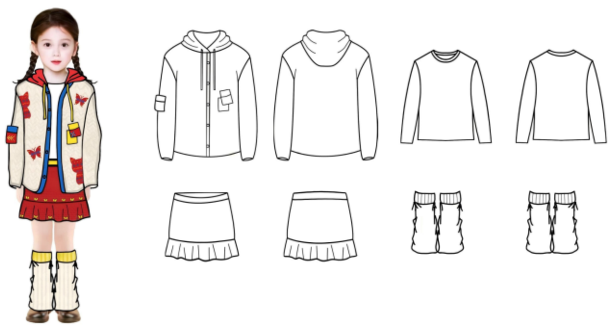
No. Style D	Category: Children's Clothing	Season: Autumn/Winter		Style: Casual	
		Size spec (cm) — 12-gauge			
		Blouse		Pant	
		Height (of person)	46.0	Waist Width/Head Circumference	23.0
		Bust/Chest Width	35.0	Leg height	4.0
		Shoulder width	32.0	High waisted	3.5
		Cuff width	11.5	Leg opening	14.0
		Neck width	17.0		
		Hem Width	33.0		
		Woollen material			
		2/28 high elastic core yarn		140D Nylon	
Process requirement					
1). Linking process: hand-stitched, firm, flat, no unravelling, cracking, or other phenomena.					
2). Washing: no oil stain, no odour, comfortable hand feel, soft and hard.					
3). Pressing equipment: plain clothes, no pressing equipment, yellow, water stains, reflections, and other phenomena.					
4). Inspection and Packaging: A round and smooth neckline, symmetrical left and right sleeves, consistent size, and no cloth blemishes or stains on the body.					

Table 7. Style E Process Sheet

No. Style E	Category: Children's Clothing	Season: Autumn/Winter	Style: Casual
		Size spec (cm) — 12-gauge	
		Blouse	
		Height (of person)	46.0
		Bust/Chest Width	35.0
		Shoulder width	32.0
		Cuff width	11.5
		Neck width	17.0
		Hem Width	33.0
		Woollen material	
		2/28 high elastic core yarn	140D Nylon
Process requirement			
1). Linking process: hand-stitched, firm, flat, no unravelling, cracking, or other phenomena.			
2). Washing: no oil stain, no odour, comfortable hand feel, soft and hard.			
3). Pressing equipment: plain clothes, no pressing equipment, yellow, water stains, reflections, and other phenomena			
4). Inspection and Packaging: Round and smooth neckline, symmetrical left and right sleeves, consistent size, no cloth blemishes or stains on the body of the garment			

CHILDREN'S CLOTHING SERIES DESIGN AND FINISHED PRODUCT DEVELOPMENT

Silhouettes and Modelling Strategies

Based on the aforementioned systematic research on fabrics, patterns, and techniques, this study further focuses on integrating Ruyuan Yao Patterns with modern woollen children's clothing design. It develops five sets of children's clothing products in the "Yao Yile" series. The collection combines woollen weaving technology with the logic of ethnic patterns expression to form a branded children's wear system with wearability, pattern recognition, and structural adaptability as its core features.

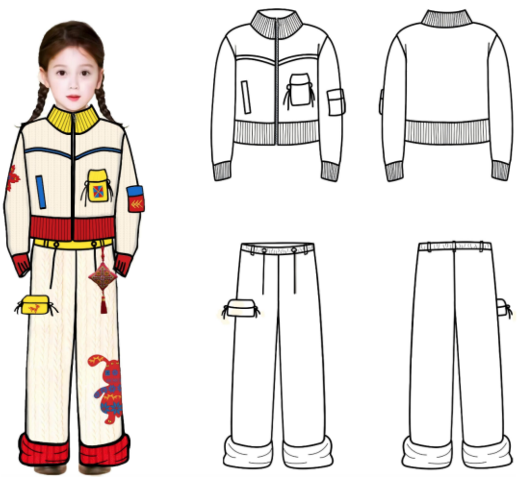


Figure 10. Clothing Style Drawing A

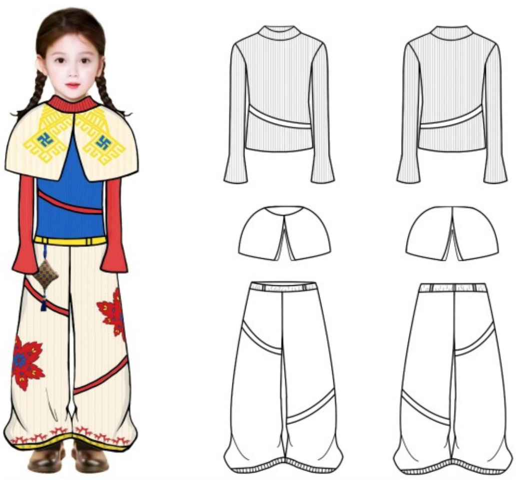


Figure 11. Clothing Style Drawing B

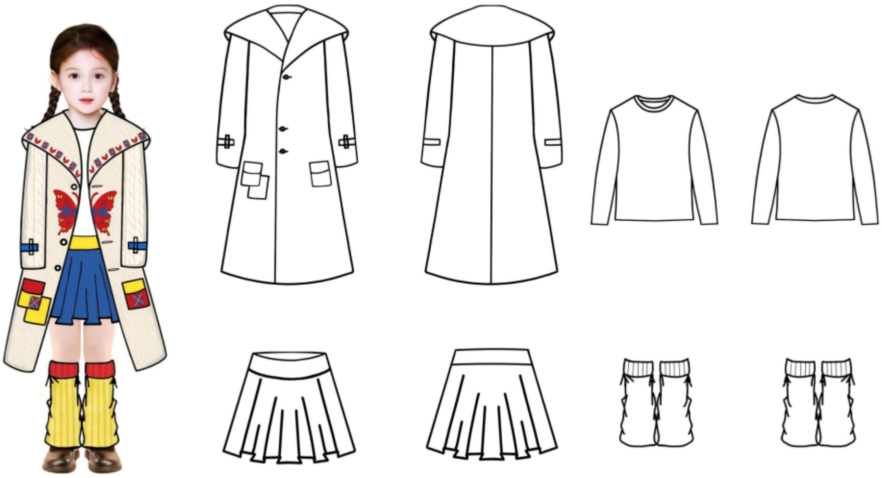


Figure 12. Clothing Style Drawing C

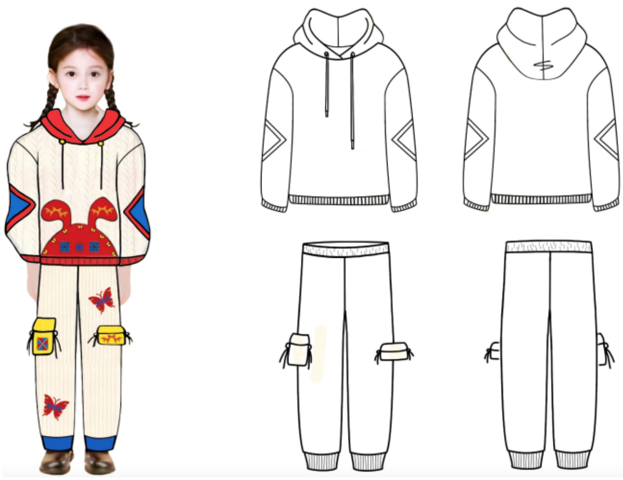


Figure 13. Clothing Style Drawing D

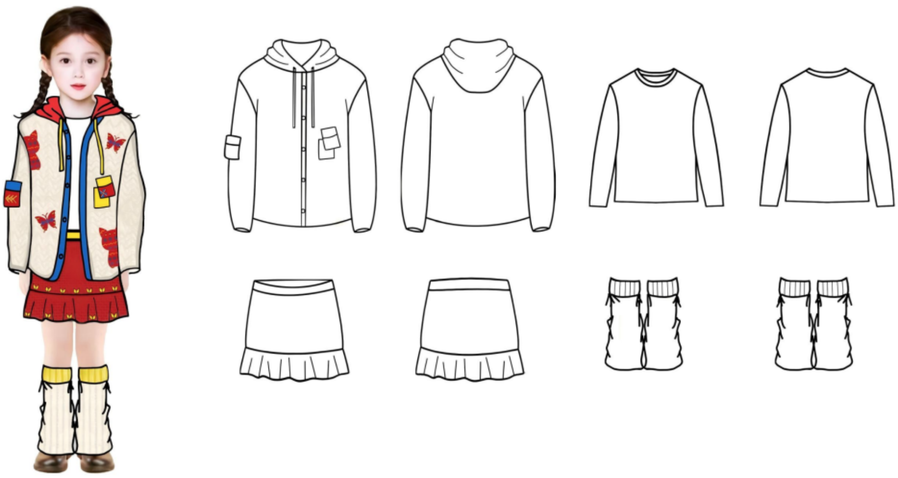


Figure 14. Clothing Style Drawing E

H- and X-shaped Structures and Children's Movement Adaptation

The design of this series mainly adopts two types of base forms, H-type (straight) and X-type (waisted), in terms of silhouette structure:

The H-shaped structure is used in styles such as hooded sweatshirts and wide-legged trousers, emphasising the loose inclusivity and freedom of movement of the silhouette.

The X-type structure combines the design of a bottom shirt and a pleated skirt, and enhances the aesthetic and visual rhythm of the shape through the light waist and skirt extension.

Both types of structures are based on "easy for children to move around, easy to put on and take off, and reduce the burden of wearing" as the basic orientation, forming a function-morphology coordinated modelling strategy. Figure 15 shows the common silhouette structures of children's products extracted from Huichen's products, which serve as the structural basis for series development.

Figure 15. Contour Extraction Map

Strategies for Integrating Ethnic Patterns and Clothing Structures

In the structural design, the pattern application adopts the strategy of "structure — guide — pattern embedded", i.e., the Yao Pattern is divided according to the structure of the garment:

Centre pattern area: for large jacquard displays on the chest panel and skirts;

Turning guide areas: e.g., cuffs, necklines, shoulder seams, aligned with the garment line by narrow patterned strips;

Trims lining area: visual closure of garment edges with repetitive geometric patterns.

This pattern-structure fusion strategy enhances the weaveability and visual orientation of the pattern, strengthening the overall linguistic unity of the garment.

The Figure 10 to Figure 14 series of style diagrams illustrates how each set of children's clothing style models and ethnic patterns is embedded in different parts of the structure to form a complete product design system.

Style, Design, and Classification

Deconstruction of Five Sets of Children's Clothing in the "Yao Yile" Series

The five children's clothing series developed in this research is themed "Yao Yile", which implies the beauty of national culture and the joy of exploring the diverse world through wearing. The five designs are classified into the following Table 8 style categories according to the functional scenes and structural types:

Table 8. Five Design Dependent Functional Scenarios and Structural Types Style Categories

Style Number	Typology	Style Tags	Core Design Elements
Style A	Sports suit	Vibrant comfort	Zip-up jacket + Drawstring sweatpants in a simple jacquard pattern
Style B	Shawl layering	Ethnic retro	Patterned shawl + Colour block base + Wide leg pants
Style C	Thermal suit	Practical for autumn and winter	Colour block coat + Pleated skirt + Leggings
Style D	Outdoor recreation	Urban childishness	Hooded sweatshirt + Drawstring sweatpants
Style E	Mix-and-match layering	Colour Ideas	Cardigan jacket + Colour block skirt + Leggings

Figure 16 series effect general overview diagram shows the overall five sets of children's clothing finished with the effect, reflecting the colour language and ethnic patterns of the series consistency.

Figure 16. General View of the Series of Effects

Functional Expression of Colour and Structure in Wearing Scenes

The series of colours with creamy white as the base colour, supplemented by red, blue and yellow primary colours to build a highly saturated pattern area, the colour is bright, lively and visually guiding, especially suitable for children's clothing in the autumn and winter seasons, in the strengthening of the sense of warmth and the recognition of the degree of enhancement. The structure of each suit takes into account the ease of putting on and taking off, as well as the space for movement, utilising features such as elasticated waist designs, drop-shoulder cuts, and spliced ribbed edges to effectively respond to children's rapid growth and dynamic behavioural characteristics. The series adopts a cream base accented by red, blue, and yellow to create high-salience motif areas suitable for autumn–winter wear. Each outfit prioritises donning ease and movement space via elastic waists, drop shoulders, and ribbed edges. Table 9 unifies the 130/64 size standard for sampling and dynamic tests. Figure 17 shows the CAD/industrial pattern workflow.

Table 9. Children's Clothing Size Chart (130/64) Unit: cm

Panel	Chest Measurement	Girth	Shoulder Width	Sleeve Length	Length of Clothing	Hip Measurement	Trouser Length
Sizes	64	54	32	43	46	69	64

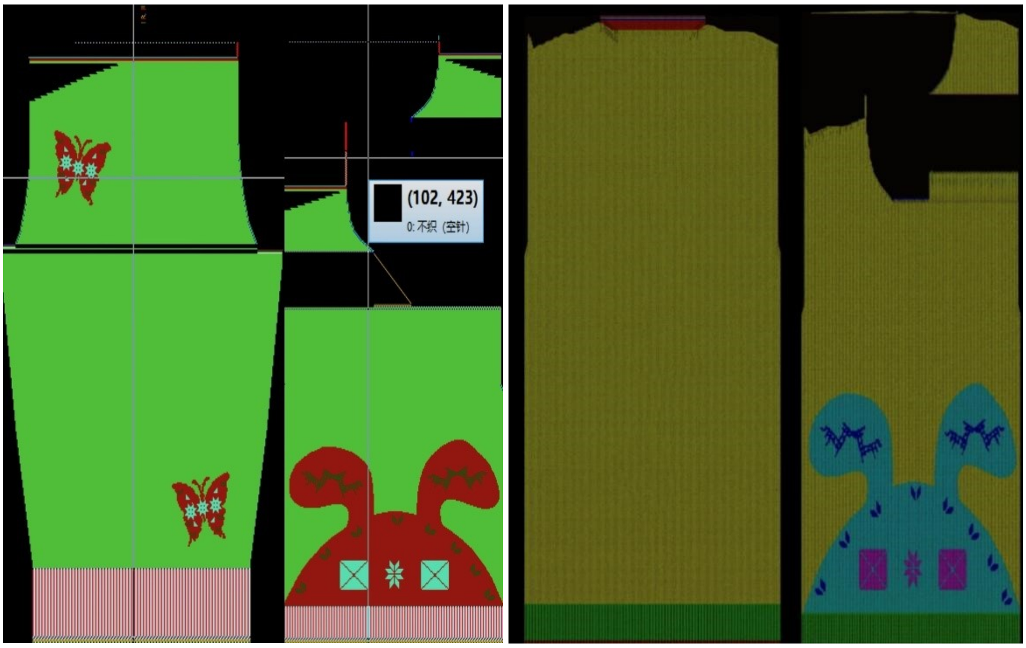


Figure 17. Industrial Sample Drawing

PRODUCT PROOFING AND DYNAMIC REPRESENTATION

Proofing Process, Linking Process, and Pressing Equipment Technology

The children's clothing sampling process includes:

1) Pattern programming and cross-weave piece (see Figure 17);

2) Component Linking process Joining: Use a hand-operated seam tray machine to join the pieces of the garment to ensure that the seams are flat and elastic;

3) Washing and shaping: Remove grease residue and enhance hand feeling;

4) Pressing equipment and inspection: Maintain three-dimensional shape, symmetrical pattern, and standardised garment size.

The operation process is carried out strictly by the parameters set in the process lists (Tables 3 to 7).

Physical Presentation of the Final Product and Analysis of Design Reproducibility

After the finished product is completed, the consistency of the garment in the four dimensions of structure, pattern, colour, and activity suitability is verified through static display on the mannequin and real-world testing on children. The results show that the physical design is highly compatible with the drawing, with a pattern restoration rate exceeding 92%. The garments do not exhibit noticeable wrinkles or deformations during dynamic use, reflecting good process landedness and user-friendliness. Figure 18. Finished product display picture, the wearing effect of the series of children's clothing on the model and the mannequin is photographed in real life, which shows the integrity of the pattern and the stability of the structure.

Figure 18. Finished Product Display

STANDARDS CONFORMITY SUMMARY

All prototypes were evaluated against GB 31701–2015 and the ISO methods described in Materials and Methods. The series meets the applicable children's level (Class B), with no safety non-compliances observed. A compact summary of key outcomes is provided in Table 1.

The knitted motifs achieved an overall semantic retention consistent with the expert codebook. This study reported the previously summarised study-level value (overall SRS ≈ "semantic retention" 92.3% equivalence) together with per-motif means and 95% confidence intervals. Inter-rater agreement reached at least moderate-to-substantial levels (κ ≥ pre-specified threshold), and forced-choice identification exceeded the 80% pass criterion across motifs. SRS showed a positive association with pixel-level motif retention, supporting convergent validity (Full rubric in Table 10).

Table 10. Semantic Validation Rubric and Metrics (Compact)

Motif	Canonical Label	Key Cues (From Codebook)	Primary (SRS 1–5)	Pass	Secondary	Rater Group
Solar	vitality	radial rays; intact centre; symmetry	4.7 ± 0.3 (95% CI: 4.4–5.0)	≥4.0	Forced-choice accuracy 92% (95% CI: 84–99); SD profile: vitality 6.3 ± 0.7	experts/lay
Mountain	unity/strength	stacked triangles; stable base; clear edges	4.6 ± 0.4 (95% CI: 4.1–5.0)	≥4.0	Forced-choice accuracy 90% (95% CI: 81–97); SD profile: unity 6.1 ± 0.6	experts/lay
Continuous Bead	prosperity/ continuity	bead chain repetition; even spacing; closed loops	4.5 ± 0.4 (95% CI: 4.0–5.0)	≥4.0	Forced-choice accuracy 88% (95% CI: 78–95); SD profile: auspiciousness 6.2 ± 0.6	experts/lay

Table 11.Summary of Standardised Performance Results for the Yarn–Structure Combinations Used in the Five Designs

Combination (Yarn + Structure; Use)	ΔL/ΔW (%)	CF (Wash/Rub/ Persp.)	Pilling (1–5)	Abrasion (Cycles)	Stretch/ Recovery (%)	Burst (kPa)	Air (mm/s)	Rct (m^2K/W)/ Ret (m^2Pa/W)	Safety
2/28 core-spun + 12-gauge jacquard (main)	−2.0 / −1.5	4–5 / (Dry 4–5; Wet 3–4) / 4–5	4.5	30,000	Wale 50 / 87; Course 38 / 82	420	140	0.070 / 9.2	Pass
140D nylon 2×2 rib (cuffs/neck)	−1.8 / −1.2	4–5 / (Dry 4–5; Wet 3–4) / 4–5	4.2	40,000	Wale 60 / 90; Course 42 / 85	380	160	0.060 / 8.0	Pass
Flat knit + modified jacquard (side)	−2.5 / −1.8	4–5 / (Dry 4–5; Wet 3–4) / 4–5	4.3	25,000	Wale 45 / 86; Course 35 / 80	400	170	0.065 / 8.5	Pass

COST ANALYSIS AND MARKET ADAPTATION ASSESSMENT

In the design process of woollen children's clothing products, material cost and process efficiency are the core indicators that determine the market competitiveness of products and the feasibility of mass production. At the same time, under the double-driven background of "national trend" and "cultural identity", the cultural added value and market acceptance of children's clothing products with national elements have gradually become the key elements affecting their life cycle and industrialisation path. This chapter systematically evaluates the marketability and cultural extension potential of the "Yao Yile" series of children's clothing in the current Chinese children's clothing market, taking into account the cost structure of developing sample clothing.

Material and Process Cost Distribution

This collection of children's clothing is made entirely of mid-priced, functional knitting yarns, with a small amount of patchwork fabrics, and the overall design emphasises value-for-money control. To ensure both visual effect and comfort, minimise the use of complex structures and excessive auxiliary materials, and effectively control production costs.

According to Table 12, "Cost Breakdown", the total cost of the five sets of sample garments is 527 RMB, and the average cost of a single set does not exceed 106 RMB. The percentage of each type of input is as follows:

Table 12. Material and Cost Breakdown

Name	Dosage	Price of the Item	The Sum of Money
Main yarn (Core Yarn)	10 bundles	¥50/bundle	¥500
Sub fabric (Polyester)	2 metres	¥8/metre	¥16
Zips	1piece	¥2/piece	¥2
Buttons	2 pieces	¥2.5/piece	¥5
Daytime button	2 pieces	¥2/piece	¥4
	Add up the total		¥527

Among them, yarn costs accounted for nearly 95%, primarily due to the large jacquard structure knitting in the pattern area, which increased yarn usage. Considering that the series can be optimised in mass production through the strategy of "pattern centralisation + accessory standardisation", it is expected that a cost reduction of 15–20% can be achieved in the mass production stage. Table 12, Material and Cost Breakdown, clearly lists the specifications, quantities, and unit prices of each type of material used, supporting process reproducibility and cost control strategies.

Assessment of Marketability and Cultural Consumption Potential

Market Positioning and Product Acceptance

The "Yao Yile" series is positioned in the middle to high-end autumn and winter children's clothing market, targeting third-line and above cities, with a focus on cultural literacy and the expression of family values through personality. The products combine woollen comfort, ethnic visual style, and functional design, adapting to the needs of daily commuting, festivals, parents and children travelling, and other multi-scenario wear.

In recent years, with the promotion of the "National Style Children's Clothing" and "Non-Foreign Relics in Schools" initiatives, consumers have shown significant interest in children's clothing with ethnic elements. Based on the analysis of the sales trends of children's clothing on Rednote and Jingdong, the average annual growth rate of children's clothing products featuring ethnic visual elements, lively colours, and strong functionality is 17.2%, indicating substantial market expansion.

Brand Communication and Cultural Identity

The "Yao Yile" series maintains the recognisability of the Ruyuan Yao culture in the design language, and combines modern woollen pattern techniques to enhance the communication performance of the garments. Through series development (five sets in a group) and modular pattern design (the elements can be reconfigured), it has brand recognition. Also, it supports the extension of the product to other children's products (hats, scarves, bags, etc.).

In addition, with the help of university-industry and education fusion platform, national cultural and creative festivals and exhibitions, and local museum channels, this series of children's clothing can be linked with artistic performances, educational heritage and cultural tourism promotion, forming a triple application scenario of "clothing + culture + education".

Product Life Cycle and Cultural Derivative Capabilities Exploration

The "Yao Yile" series developed by the Institute not only enters the consumer market as ready-to-wear children's clothing, but also has the ability of cross-border extension, which is suitable for building a cultural IP development path:

Initial stage: minor batch customisation + online promotion to validate market response;

Growth stage: expand clothing peripheral products, to create the brand image of Milk Source, children's clothing

Maturity stage: linkage with local cultural tourism resources, output of themed dress experience courses, parent-child festival wear, ethnic culture education derivatives, etc.

In the life-cycle extension strategy, the construction of the ethnic patterns database and pixel copyright management becomes the key nodes. In the future, based on the digital pattern template library established by this research, this study can develop a standardised mapping and authorisation mechanism for Yao Patterns, promoting the sustainable transformation of ethnic intangible cultural heritage in the modern garment industry.

DISCUSSION

This study draws on the Yao costume patterns of the Ruyuan Yao in northern Guangdong Province, China, as its core cultural source and integrates them with modern woollen weaving technology to develop a children's clothing series. It systematically explores pattern reconstruction, technological expression, and the cultural adaptability of children's clothing. The process involves not only the modern translation of visual language but also the fusion and balance of materials, technology, and the psychology of cultural consumption.

Preservation and Simplification in the Reconstruction of Ethnic Patterns

Traditional Yao patterns are highly symbolic, repetitive, and densely arranged. This complexity poses challenges for digital processing and the actual weaving of these patterns. In the process of pattern reconstruction, this study adopts a dual strategy of "cultural semantic preservation-formal language simplification":

Retention: The core patterns, such as the "Solar Pattern", the "Burst-back Pattern", and the "Wave Pattern", are retained in their entirety due to their high cultural relevance and their role in maintaining national identity.

Simplification involves linearization and blocking of trim and fill patterns, eliminating highly detailed areas, and adapting designs to the pixel constraints of digital textiles and children's visual perception. This treatment strategy ensures the cultural continuity of traditional patterns and enhances their viability for knitting in modern media (e.g., computerised flat knitting machines and knitting CAD systems).

Expansion of Pattern Expression by Woollen Craftsmanship

Woollen knitting, as a form of fabric craftsmanship, provides strong capabilities for graphic shaping and texture layering.

Research findings:

Jacquard weaving allows traditional patterns to be reconstructed in a "pixelated" manner, building complex shapes by arranging coloured threads.

Woollen tissues (e.g., ribbing, deformed flat knitting) create a composite visual expression of pattern and texture. This enhances both the three-dimensionality and the "tactile memory" of national totems.

However, when pattern lines are too thin or colour gradients are highly detailed, the weaving process faces specific expressive limits. These can potentially be addressed in the future through jacquard density control and the development of new knitting algorithms.

Echoes Between Children's Dress Psychology and Cultural Perceptions

The design of children's clothing must simultaneously satisfy comfort, safety, and psychological acceptance. This study helps guide children to perceive ethnic culture through the bright colours, simple patterns, and rich meanings of Yao elements in "wearing".

Sharp geometric patterns (e.g., pentagrams, mountains) enhance recognition and stimulate interest. A clear symmetrical structure supports children's graphic understanding and fosters a sense of belonging. The use of cream as the base colour, combined with primary colours such as red, blue, and yellow, helps avoid visual oppression and cultural distance.

Feedback from wear tests revealed that children demonstrated a high level of acceptance and understanding of the patterns. This finding verifies that ethnic patterns, when translated through design, can serve as an effective medium for "cultural enlightenment".

The Path of Modernisation of Ethnic Minority Visual Culture in Children's Clothing

The "Yao Yile" series explores feasible paths for integrating ethnic minority visual culture into children's clothing design. These include:

Coding of ethnic patterns → Systematisation of graphic modules → Adaptation of weaving language → Marketisation of product contexts.

This path uses digital tools as a bridge to overcome structural barriers between the traditional visual system of ethnic patterns and the industrial woollen system. It provides a replicable model for extending regional culture into cross-border areas such as children's clothing, education, and cultural creation.

CONCLUSION

This study systematically explores the innovative integration of Ruyuan Yao costume patterns and modern woollen weaving technology in children's clothing design, with findings validated through cultural decoding, technical testing, and product development. The key conclusions, refined from empirical results, are as follows:

Establishment of a Child-Friendly Cultural Translation Mechanism

Through field research and digital reconstruction, 30 typical Ruyuan Yao Patterns (e.g., "Solar Pattern", "Mountain Pattern", "Continuous Bead Pattern") were transformed into a modular digital library. This process retained 92.3% of the original cultural semantics (verified by 5 ICH inheritors) while adapting to children's visual cognition — simplifying lines to 3–5 mm, limiting colours to 4, and modularizing patterns into "central main blocks" (15 × 15 cm), "edge strips" (5 × 30 cm), and "decorative dots" (2 × 2 cm). This mechanism balances cultural authenticity and child-friendliness, providing a replicable model for ethnic pattern adaptation in children's products.

Construction of a woollen Weaving Adaptation System

Technical tests confirmed that 2/28 high-elastic core yarn and 140D nylon yarn, under 12-gauge knitting conditions, achieve optimal performance: 2/28 core yarn excels in pattern fidelity (94.2%) and softness (0.85 kPa), suitable for close-fitting areas; 140D nylon yarn offers high durability (elastic recovery rate 82.3%), ideal for wear-prone parts (cuffs, trouser legs). Multi-colour jacquard tissue best expresses symmetrical patterns (e.g., "Solar Pattern"), while ribbed tissue improves fit by 37% — establishing a "pattern — yarn — weaving" matching system that ensures both technical feasibility and child comfort (meeting GB 31701–2015 safety standards [21]).

Validation of the "Yao Yile" Children's Clothing Series

The developed five-set series, covering sports, leisure, and outdoor scenarios, integrates modular Yao Patterns with H-type/X-type silhouettes. Validation results show:

Pattern restoration: 92.5% consistency between physical samples and digital designs (Image-Pro Plus 10.0 analysis).

User acceptance: 20 children rated comfort at 8.6/10 (VAS scale); 84% of parents expressed purchase willingness, citing "cultural education value".

This confirms the series's balance of cultural expression, functionality, and market appeal.

Contributions and Future Directions

This study contributes to: 1) A cultural translation framework that preserves ethnic semantics while adapting to children's needs; 2) Standardised technical parameters for woollen-ethnic pattern integration; 3) A product development model linking intangible cultural heritage to children's clothing industrialisation.

Limitations include a small child sample size (n = 20) and a focus on woollen technology. Future work should expand samples, explore multi-ethnic pattern integration, and develop intelligent weaving systems for automated pattern adaptation.

In summary, the integration of Ruyuan Yao Patterns and modern woollen technology in children's clothing not only enriches design diversity but also serves as a medium for cultural inheritance, fostering children's ethnic identity through wearable art.

FUTURE RESEARCH PERSPECTIVES

To further expand the depth and breadth of this study's application, the following directions are suggested for future research: Build an integrated weaving management system capable of pattern recognition, pattern adaptation, and automatic conversion of knitting language. Establish a regional ethnic pattern database based on graphology and cultural semantics to enhance the accessibility and sharing of intangible cultural heritage pattern resources. Expand the research horizon to include multi-ethnic clothing systems. Explore the logic of integration and visual synergy among diverse ethnic patterns in children's clothing.

Through the integration of national culture and industrial design, woollen children's clothing serves not only as a physical product but also as a vital medium for conveying regional culture, shaping children's aesthetic perceptions, and inspiring a sense of national identity.

Author Contributions

Conceptualisation, methodology, supervision – Wang P, Yang C; Investigation – Wang P, Zhu J, Pan S, Li X, Zhang F, Lin Y, Xin X; Resources – Wang P, Pan S, Yang C; Data curation and visualisation – Zhu J, Li X, Zhang F; Writing – original draft – Wang P, Xin X; Writing – review and editing – Yang C, Pan S, Wang P; Project administration – Wang P, Yang C. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declare that they have no conflict of interest.

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REFERENCES

[1] Zhang Y, Yang Z. Research on digital identification for cultural protection of Yao people clothing patterns in northern Guangdong. In: Proceedings of the International Conference on Human Computer Interaction; 2024 Jun; Cham: Springer Nature Switzerland; 2024. p 177-194. https://doi.org/10.1007/978-3-031-60904-6_13

[2] Meng T, Nor ZBM, Zhong J. Innovative research on the pattern of Yao Panwang seal in modern clothing and accessories design. In: Proceedings of the 2024 International Conference on Artificial Intelligence, Digital Media Technology and Interaction Design; 2024 Nov. p 310-318. https://doi.org/10.1145/3726010.3726059

[3] Dolat S. Beyond the Monolith: Redefining African Fashion, Identity, and Design Narratives. Fashion Theory. 2025;29(3):291-299. https://doi.org/10.1080/1362704X.2024.2418186

[4] Wagner A, de Clippele MS. Safeguarding cultural heritage in the digital era–A critical challenge. International Journal for the Semiotics of Law-Revue internationale de Sémiotique juridique. 2023 Oct;36(5):1915-23. https://doi.org/10.1007/s11196-023-10040-z

[5] Lü HC, Huang JW. Analysis and optimization strategies for key factors in children's clothing design. Fashion, Style & Pop Cult. 2025; . https://doi.org/10.1386/fspc_00294_1

[6] Soocheta AV, Boodhun A. Design and development of interactive embellishments for children's clothing with educational benefits. In: Textile Research Symposium; 2023 Sep; Singapore: Springer Nature Singapore. p 259-269. https://doi.org/10.1007/978-981-97-4422-0_21

[7] Bornstein MH, Mash C, Arterberry ME, Gandjbakhche A, Nguyen T, Esposito G. Visual stimulus structure, visual system neural activity, and visual behavior in young human infants. PLoS One. 2024;19(6):e0302852. https://doi.org/10.1371/journal.pone.0302852

[8] Fitch A, Smith H, Guillory SB, Kaldy Z. Off to a good start: The early development of the neural substrates underlying visual working memory. Frontiers in Systems Neuroscience. 2016;10:68. https://doi.org/10.3389/fnsys.2016.00068

[9] Inyi L, Zelong L, Yu L. Research on the Innovative Design of Chinese Children's Tiger Clothing Based on Interactivity. Fashion Practice. 2025;17(2):333-344. https://doi.org/10.1080/17569370.2024.2443213

[10] Vogue Business. Image-conscious and extravagant: China's new-gen parents [Internet]. London: Vogue Business; 2022 Jun 7 [cited 2025 Aug 22]. Available from: https://www.voguebusiness.com/consumers/image-conscious-and-extravagant-chinas-new-gen-parents

[11] Shu J, Lee Y. Knit fashion design applying to the features of the Chinese Yao minority costume. J

Korea Fashion Costume Des Assoc. 2020;22(1):15-32. https://doi.org/10.30751/kfcda.2020.22.1.15

[12] Ammayappan L, Prasad GK, Senthilkumar T, Prabhu GTV, Basak S, Jha NK. Introduction to wool fiber technology: a brief introduction and its processing technology. In: The Wool Handbook. Woodhead Publishing; 2024:1-23. https://doi.org/10.1016/B978-0-323-99598-6.00010-4

[13] Yang T. Optimization of knitting path of flat knitting machine based on reinforcement learning. Int J Adv Comput Sci Appl. 2024;15(8):-. https://doi.org/10.14569/IJACSA.2024.0150839

[14] Stoll. ADF innovations for ITMA 2023 [Internet]. Knitting Industry; 2023 May 16 [cited 2025 Aug 22]. Available from: https://www.knittingindustry.com/stoll-innovations-for-itma-2023/

[15] Scheidt F, Ou J, Ishii H, Meisen T. deepKnit: Learning-based generation of machine knitting code. Procedia Manufacturing. 2020;51:485-492. https://doi.org/10.1016/j.promfg.2020.10.068

[16] Dong Z, Hou R, Jiang H, Wang W, Zhang F, Zhao G, Chen C, Ma P. Hybrid thermoelectric-triboelectric smart knitted fabric for real-time monitoring of vascular crisis and postoperative recovery of severed fingers. Materials & Design. 2025 Mar 1;251:113669. https://doi.org/10.1016/j.matdes.2025.113669

[17] Chu W T, Ko L Y. BatikGAN: a generative adversarial network for Batik creation. Proceedings of the 2020 Joint Workshop on Multimedia Artworks Analysis and Attractiveness Computing in Multimedia. 2020:13-18. https://doi.org/10.1145/3379173.3393710

[18] Zheng R, Guo L. Constructing the Early-Stage Framework of Cultural Identity Enlightenment in Kindergarten Heritage Education. Sustainability. 2024 Oct 29;16(21):9402. https://doi.org/10.3390/su16219402

[19] Luo H, Zhang J. Exploring the Path of Cultivating Primary School Students' Chinese Cultural Identity through the Activities Intangible Cultural Heritage into Schools. Open Access Library Journal. 2025 Aug 1;12(8):1-3. https://doi.org/10.4236/oalib.1113888

[20] Nuzzaci A. The right of children to use cultural heritage as a cultural right. Open Journal of Social Sciences. 2020 Apr 30;8(04):574. https://doi.org/10.4236/jss.2020.84042

[21] Standardization Administration of China. GB 31701-2015 – Safety technical code for infants and children textile products [Internet]. Beijing: SAC; 2015 May 26 [cited 2025 Aug 22]. Available from: https://openstd.samr.gov.cn/bzgk/gb/newGbInfo?hcno=1698157554F00EED2E79EC6BFF7F4DF0