Innovative Transformation Design of Intangible Cultural Heritage Textile Skills in Rural Regional Architectural Space—Interdisciplinary Design Exploration Based on Jianghuai Weibao

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ABSTRACT The adaptive integration of intangible cultural heritage textile techniques into contemporary rural architecture requires simultaneous consideration of material performance, spatial functionality, and cultural continuity. This study proposes an interdisciplinary transformation framework for Jianghuai Weibao architecture by coupling composite textile materials, parametric spatial design, and community-based construction strategies. Ramie fabrics are enhanced through epoxy-resin composite modification to improve mechanical durability and environmental adaptability, while traditional embroidery patterns are converted into parametric shading components capable of regulating daylight and spatial perception. Mortise-and-tenon modular weaving structures are further introduced to simplify installation and promote participatory construction. Experimental results demonstrate that the optimized composite ramie fabric achieves a tensile strength of 21.33 MPa, parametric hollowing enables controllable indoor illumination with a strong linear correlation to porosity, and modular assembly improves installation efficiency from 1.2 to 3.4 pieces per minute. Community evaluation indicates high levels of learnability and cultural identity, with satisfaction indices reaching 0.88 and 0.92, respectively. Beyond heritage conservation, the proposed methodology illustrates how functional textile composites and parametrically engineered surface morphologies can support adaptive regulation of light transmission and energy-related environmental interactions, providing a transferable design paradigm for intelligent architectural envelopes and multidisciplinary engineering applications involving wave–material interaction and spatial performance optimization.

INDEX TERMS composite textile materials, parametric spatial design, architectural envelopes, light transmission regulation, intangible cultural heritage

I. INTRODUCTION

TRADITIONAL textile techniques embody the wisdom of regional production and aesthetic cognition, with their craft logic containing unique cultural genes. In the context of rural revitalization, these skills offer potential for the renewal of traditional settlements like the Jianghuai Weibao. As a defensive settlement, the Weibao is characterized by thick walls, small window openings, and inward-facing courtyards, which impose specific constraints on the physical environment and functional requirements. At present, the application of intangible cultural heritage textile techniques in Weibao mostly stays at the implantation of decorative symbols, and fails to break through the technical barriers between material performance limitations and spatial functional requirements [1,2]. Historically, ramie fabric sunshade, reed woven partition and other skills have a symbiotic relationship with space. However, in modern applications, due to the lack of weather resistance of traditional fabrics and the disconnection between embroidery patterns and physical properties, the skills have fallen into the dilemma of static display. At the same time, the renewal of Weibao relies on the logic of urbanization, ignores the potential of local crafts, and exacerbates cultural homogenization [3,4]. The core contradiction lies in the lack of technical paths to transform intangible cultural heritage crafts into functional requirements such as heat insulation and light transmission, as well as the lack of design methods to build a synergistic mechanism between skill activation and space renewal. In the context of this study, the term "Intangible Cultural Heritage Textile Skills" specifically refers to three core traditional crafts prevalent: the hand-weaving technique of ramie fiber into fabric, the geometric symmetrical embroidery patterns unique to the locality, and the traditional reed weaving craft used for spatial partitions. The research focuses on preserving and transforming the logic of these specific techniques—the materiality of ramie, the compositional principles of embroidery, and the structural logic of reed weaving—rather than their symbolic forms alone.

In recent years, research on the integration of intangible cultural heritage and architectural space has made progress in multiple dimensions. Pavlos Chatzigrigoriou et al. [5] used the HERMeS method and digital tools to reveal the visual recording mechanism of intangible cultural heritage elements in traditional settlements on Aegean islands, providing a theoretical framework for the digital protection of cultural heritage. Chuan He et al. [6] found the clustered coupling characteristics of intangible cultural heritage and village layout in the Dongting Lake Basin, revealing the synergistic effects of natural environment and policy intervention on spatial pattern. Qianming Xue et al. [7] found that the intangible cultural heritage in the upper reaches of the Yellow River showed a "multi-core agglomeration" spatial differentiation through kernel density analysis and distribution equilibrium model, and proposed its integrated development path based on multiple factors such as urbanization rate, altitude and policy. David Heesom et al. [8] proposed the HBEP (Heritage BIM Execution Plan) execution framework, integrating tangible building data and intangible cultural heritage information through collaborative heritage building information modeling methods. They constructed a multibuilding three-dimensional model of the 19th century industrial site in the UK, providing an innovative solution for the protection and revitalization of industrial heritage that integrates historical value and modern BIM (Building Information Modeling) technology. Salah Mahdi Saleh Al-Adilee et al. [9] proposed a narrative expression path for local materials from the perspective of semiotics. Regarding the Weibao, Xie Liang et al. [10] analyzed it from the perspective of the changes and development of multiple spatial attributes, revealing the diversified mechanism of its spatial attributes with social changes. However, existing research has not yet solved a key problem: how to transform specific intangible cultural heritage skills into technical paths that meet the functional requirements of the Weibao space, especially the lack of systematic solutions in terms of material performance transformation, process parametric reconstruction and community co-construction mechanisms.

To this end, this paper constructs a research framework centered around "new materials/processes—spatial applications—user experience." Specifically, at the material level, ramie fabric is modified through composite processing to enhance its mechanical properties and environmental adaptability, providing technical support for its integration into architectural spaces. At the design level, a parametric approach is employed to translate traditional embroidery patterns into spatial components, achieving the dual goals of light regulation and cultural expression. At the structural level, a modular solution based on mortise and tenon joints is proposed to lower the construction barrier and enhance community participation. At the application level, a questionnaire survey and a fit evaluation model are combined to examine user feedback on functionality, aesthetics, comfort, and cultural identity. Within this research framework, this paper further proposes the following hypotheses to clarify the research logic and facilitate subsequent verification: H1: Composite modified ramie fabric can maintain the cultural characteristics of traditional craftsmanship while meeting the performance requirements of architectural space for strength and weather resistance; H2: The porosity of embroidery pattern components generated based on a parametric method is significantly correlated with the indoor light regulation effect; H3: The intervention of mortise and tenon modular splicing can enhance resident participation and, to a certain extent, strengthen the community's cultural identity and spatial satisfaction. This framework aims to construct a revitalization paradigm that integrates cultural depth and technical feasibility, providing theoretical contributions and practical references for the revitalization of intangible textile heritage in contemporary rural space design.

II. TECHNICAL PATH FOR THE INTEGRATION OF INTANGIBLE CULTURAL HERITAGE TEXTILE SKILLS AND JIANGHUAI WEIBAO ARCHITECTURAL SPACE

A. OVERALL DESIGN FRAMEWORK FOR THE TRANSFORMATION OF INTANGIBLE CULTURAL HERITAGE TEXTILE SKILLS IN WEIBAO SPACE

In view of the special regional spatial characteristics of Jianghuai Weibao, the overall design framework of the transformation path in this paper is shown in Figure 1.

The framework shown in Figure 1 is driven by the functional requirements and cultural characteristics of the Weibao, and constructs a systematic transformation path of "pain point identification-technology responseexperimental verification-community iteration". The material performance optimization module prepares high-strength and weather-resistant CRF (Composite Ramie Fabric) materials through epoxy resin impregnation and modification. The process translation and reconstruction module uses parametric tools to transform embroidery patterns into light and shadow control components; modular structural implantation develops mortise and tenon joint modules based on reed weaving to improve installation and maintenance efficiency. The community co-construction mechanism runs through the whole process, organizing villagers to participate in production workshops, collecting feedback to optimize material selection, process flow and module design, and forming a dynamic iterative activation path. Finally, the spatial adaptability assessment module uses the hierarchical analysis method to quantify the component matching weights of different spatial units.

This framework forms a dynamic closed loop: the spatial needs of the Weibao drive the design, community feedback and adaptation assessment are converted into optimization

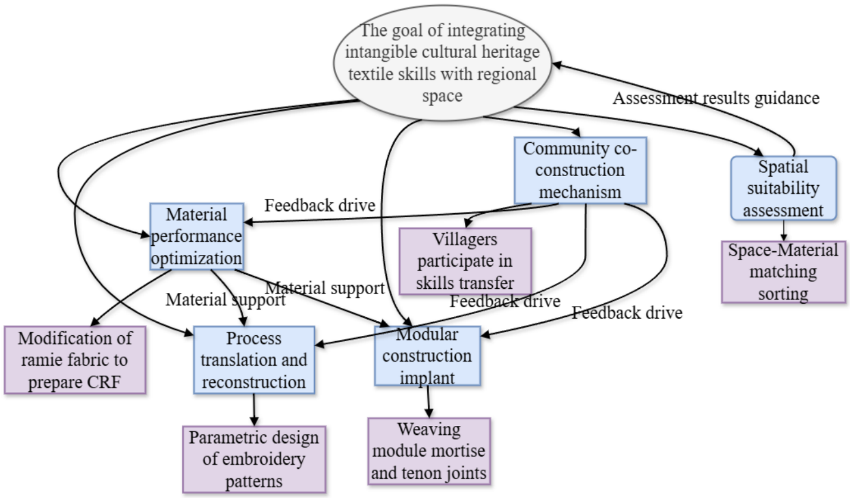

FIGURE 1. Overall framework of textile technology and space integration

parameters, and continuous iteration ensures that the solution fits the local characteristics of the Weibao.

In order to clarify the hypotheses and the relationship between independent variables, dependent variables and mediating variables, we designed a research logic model as shown in Table 1.

Table 1 presents the research logic model of this study. The independent variables include material treatment, parametric design, and modular assembly strategies, while the mediating variables reflect performance improvements, environmental regulation, and construction efficiency. The dependent variables focus on spatial adaptability, user satisfaction, and cultural identity. These variable relationships form the basis for the research hypotheses (H1–H3) and guide the subsequent experimental validation and application analysis.

B. MATERIAL PERFORMANCE OPTIMIZATION: IMPROVED ADAPTABILITY OF RAMIE COMPOSITE FABRICS TO WEIBAO

In response to the defensive wall requirements of Jianghuai Weibao, this link modified the traditional ramie fabric, using epoxy resin and polyurethane curing agent to impregnate and composite the ramie fabric, and finally formed a composite ramie fabric CRF [11,12]. The material modification process is shown in Figure 2.

The modification process used a commercially available bisphenol-A epoxy resin and a polyetheramine curing agent. The resin was diluted with acetone to achieve three target concentrations: low (10 wt%), medium (20 wt%), and high (30 wt%). The curing agent was added at a fixed mass ratio of 1:0.8. Cleaned ramie fabric samples were immersed in the resin solution for 30 minutes at room temperature (25°C), followed by airdrying for 2 hours and a final curing step in an oven at 80°C for 4 hours.

In order to quantify the improvement of the mechanical properties of CRF, its warp breaking force and elongation were tested according to the ASTM D5035 (Strip/Grab Test) standard. The breaking stress σ (MPa) was then calculated based on the measured breaking force and the specimen's cross-sectional area using Formula (1):

$$\sigma = \frac{F}{A} \tag{1}$$

In formula 1, F is the maximum load when the sample breaks, and A is the cross-sectional area of the sample. The improvement of the longitudinal breaking strength and initial modulus of CRF indicates that the composite modification effectively enhances the stress transfer efficiency between fibers. In order to meet the lighting standards of the wall of the Weibao, the light transmittance test uses a spectrophotometer CP-EFlat to measure the average light transmittance T of CRF in the visible light band, and the calculation formula is:

$$T = \frac{I}{I_0} \times 100\% \tag{2}$$

In formula 2, I is the light intensity transmitted through CRF, and I_0 is the incident light intensity. The thermal conductivity is measured by the ASTM (American Society of Testing Materials) standard steady-state method to evaluate the potential of CRF to improve the thermal insulation performance of the Weibao. The schematic diagram of the fabric tensile test and light transmittance test equipment is shown in Figure 3.

The above experimental method effectively solves the pain points of insufficient strength, poor light transmittance, and weak thermal insulation of traditional fabrics through material modification, laying a material science foundation for the functional implantation of intangible cultural heritage materials in the defense system of the Weibao.

Our innovation lies in its customized application to the Weibao built environment. Specifically, we optimized the resin concentration and curing process to achieve a balance between tensile strength, visible light transmittance, and thermal insulation performance—a combination not commonly found in commercial shading materials such as metal

TABLE 1. Research logic and variable relationships

Variable category	Specific variables	Illustrate	Corresponding hypothesis
Independent variables	Textile material processing methods	Epoxy resin composite modification of ramie fabric	H1
	Parametric design method	Embroidery pattern vectorization and Grasshopper parametric modeling, with controllable hollowing rate	H2
	Modular splicing method	Mortise and tenon weaving module and community workshop co-construction mechanism	H3
Mediating variables	Composite fabric performance indicators	Tensile strength, weather resistance, light transmittance	H1
	Environmental control function	Light distribution and shading efficiency	H2
	Construction efficiency	Splicing speed and replaceability	H3
Dependent variables	Spatial adaptability	The degree of matching between fabric/components and the "WeiBao" space	H1–H3
	Villager satisfaction	Functionality, aesthetics, comfort, and learning	H1–H3
	Cultural identity	Residents' recognition of the application of textile techniques in architecture	H3

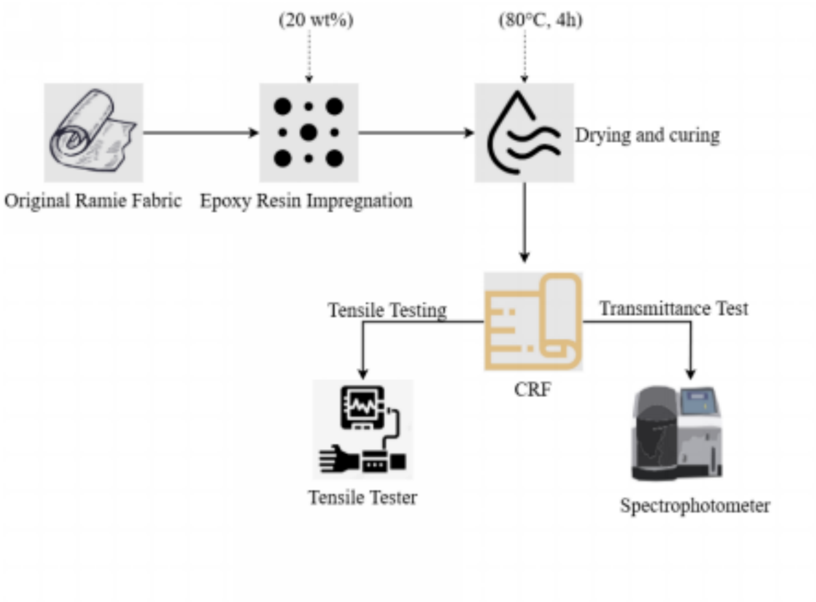

FIGURE 2. Composite fabric modification process

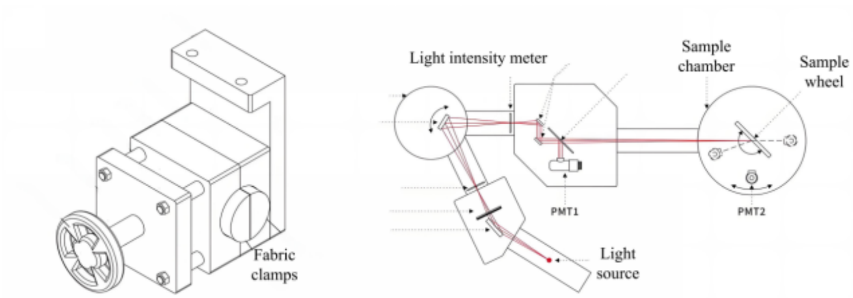

FIGURE 3. Testing Devices for Mechanical and Optical Performance

mesh or synthetic fibers. Unlike traditional materials, our CRF retains cultural texture, enables diffused light suitable for Weibao's small window spaces, and supports modular, handcrafted assembly by the local community, thus perfectly combining technical performance with socio-cultural adaptability.

C. PARAMETRIC LIGHT AND SHADOW CONTROL DESIGN OF EMBROIDERY PATTERNS

Based on the composition logic of geometric symmetrical patterns in traditional embroidery, representative patterns are selected as design motifs, which are vectorized through digital image processing technology. Sunshade components with both cultural expression and physical environment regulation functions are designed, and the Grasshopper visual programming module in the Rhino platform is imported for parametric modeling [13]. In Grasshopper, the vectorized pattern is decomposed into a base unit, which is then parameterized and converted into apertures using the Boundary Surfaces component; the hollowing rate is calculated as the ratio of aperture area to total area, while the Graph Mapper and Jitter components preserve the pattern's cultural rhythm and handcrafted aesthetic.

In the process of parametric model construction, the basic cell size is defined, and the hollowing rate R is introduced as the core control variable. Its calculation formula is:

$$R = \frac{A_{\text{hole}}}{A_{\text{total}}} \times 100\% \tag{3}$$

In Formula 3, A_{hole} represents the area of the hollow area in a single pattern unit, and A_{total} represents the total area of the unit. By adjusting the value R range between 15% and 60%, the light and shadow penetration ratio of the fabric surface is controlled to adapt to the indoor lighting requirements under the small window cavity structure of the Weibao building.

This paper further combines the sunshine simulation plug-in Ladybug, inputs the local hourly solar radiation data throughout the year, and simulates the impact of textile components on indoor light intensity under different hollowing rates. The 'small window cavity' in the simulation is defined as a representative window type in Jianghuai Weibao architecture, with dimensions of 1.2 m (width) × 1.5 m (height), oriented southward, and surrounded by a 0.3 m thick rammed earth wall with a 0.8 m deep cavity. The Ladybug plugin was used to simulate annual solar radiation based on local climate data. A linear regression model is established to express the relationship between the indoor illumination value E and the hollowing rate R:

$$E = k_1 \cdot R + b \tag{4}$$

In formula 4, k_1 is the illumination response coefficient, which reflects the illumination gain caused by the change of unit hollowing rate; b is the intercept term, which represents the basic illumination level in the non-hollowing state.

The simulation results yielded the linear regression parameters: the illumination response coefficient $k_1 = 2.15$ lux/% and the intercept $b = 87.3$ lux. The coefficient of determination R^2 was 0.96, indicating a strong linear correlation between porosity R and indoor illumination E, thus statistically validating Hypothesis H2. Finally, the optimized parameterized pattern is output as a laser cutting template for the production of hollow sunshade panels of epoxy resin composite ramie fabric, ensuring that the pattern retains the cultural characteristics of embroidery and meets the actual functional requirements of lighting and thermal environment regulation in the Weibao space. The process of converting embroidery patterns into parametric shading components is shown in Figure 4.

The process shown in Figure 4 begins by designing the original embroidery pattern and vectorizing it into simplified outlines suitable for computational manipulation. These vectorized forms are then imported into Grasshopper for parametric modeling, where the openwork ratio (R) is defined as a controllable variable to generate multiple design variations. Finally, the parametric results are combined with composite ramie fabric to materialize the openwork sunshade components. This workflow demonstrates how intangible cultural patterns can be systematically transformed into functional architectural elements.

D. MODULAR SPATIAL IMPLANTATION OF WEAVING TECHNOLOGY

Based on the traditional reed weaving technology, a unitized weaving module with a mortise and tenon joint structure is designed. The mortise and tenon structure splicing process is shown in Figure 5.

The basic grid structure is constructed by orthogonal warp and weft weaving method, and the mechanical stability and deformation adaptability of the module are controlled by adjusting the warp and weft density and interlacing angle [14-15].

In the modular structure design, the unit side length is set to a, and the module surface density M_s (g/m^2) is calculated by the following formula:

$$M_s = \frac{W}{a^2} \times 10^6 \tag{5}$$

In formula 5, W is the mass of a single module. This parameter serves as a lightweight constraint indicator related to handling, suspension load, and modular assembly feasibility, while the structural rigidity is primarily ensured by the weaving density and the mortise-and-tenon joint design.

In order to achieve boltless assembly between modules, a mortise and tenon joint structure is introduced. Its key parameters are the tenon length L_t and the mortise depth D_m, which must meet the matching tolerance relationship:

$$\Delta = |L_t - D_m| \leq T_s \tag{6}$$

In Formula 6, T_s is the structural design tolerance, typically not exceeding 0.5 mm, which ensures the shear resistance and stability of the overall structure after module splicing. The design parameters fully consider the feasibility of villagers' hand-made production under the premise of ensuring structural stability. To enable low-skill assembly, the mortise-and-tenon joint was intentionally simplified with a tapered design, which allows for an increased assembly tolerance $T_a \leq 2$ mm. This high-tolerance design compensates for manufacturing and alignment variations, enabling easy plug-in connection and disassembly for maintenance by nonprofessional villagers without compromising the overall stability ensured by the structural design tolerance. The module surface adopts local encrypted weaving technology

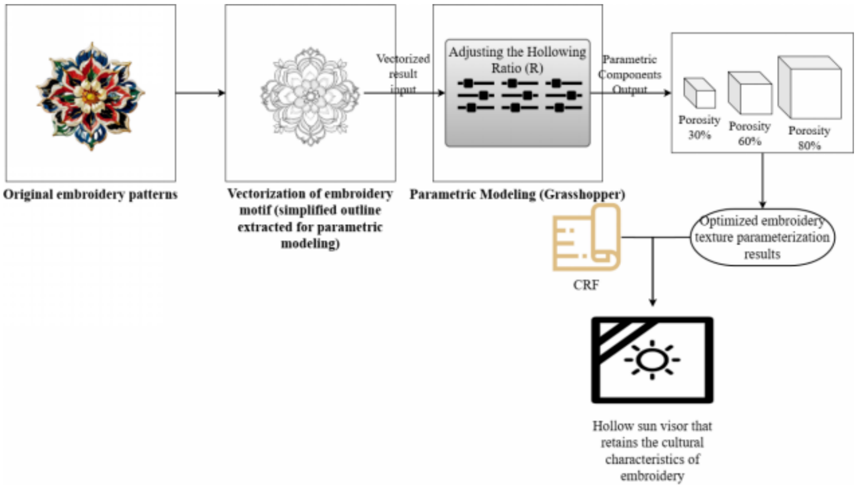

FIGURE 4. Embroidery pattern conversion process

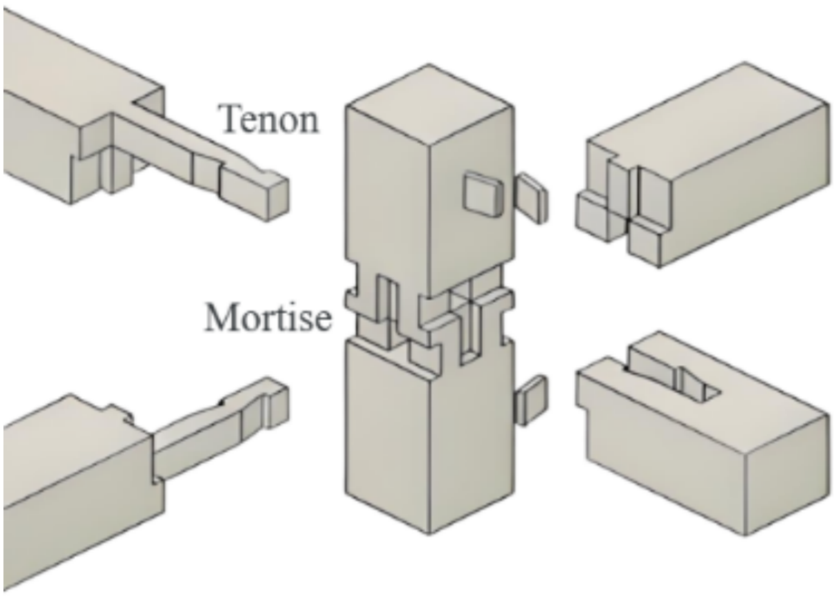

FIGURE 5. Schematic diagram of mortise and tenon structure splicing

to enhance the bearing capacity of the node while ensuring overall air permeability. The yarn coverage C of the encrypted area is defined as:

$$C = \frac{n_{\text{warp}} \cdot d_{\text{warp}} \cdot a + n_{\text{weft}} \cdot d_{\text{weft}} \cdot a}{a^2} \times 100\% \quad (7)$$

In formula 7, n_{warp} and n_{weft} are the numbers of warp and weft yarns within the encrypted area of side length a, and d_{warp} and d_{weft} are the corresponding yarn diameters. This parameter reflects the area proportion occupied by the yarns within the encrypted zone. Figure 6 shows the brief spatial effect of the mortise and tenon woven screen after splicing.

Figure 6 briefly illustrates the application of mortise and tenon woven modules within the courtyard space. The central screen is composed of multiple rectangular modules (mortise and tenon joint structure), each with internal openings to enhance light transmission. A dashed line is added to the top to simulate sunlight filtering through the modules into the space. The orthogonal woven grid of the rectangular modules also reflects their wind-resistant function as a courtyard partition. The gray rectangles on either side represent the courtyard walls, while the bottom represents the courtyard floor. The prefabricated modules were assembled on-site through simple plug-in operations, creating a light-transmitting, wind-resistant partition, demonstrating that the

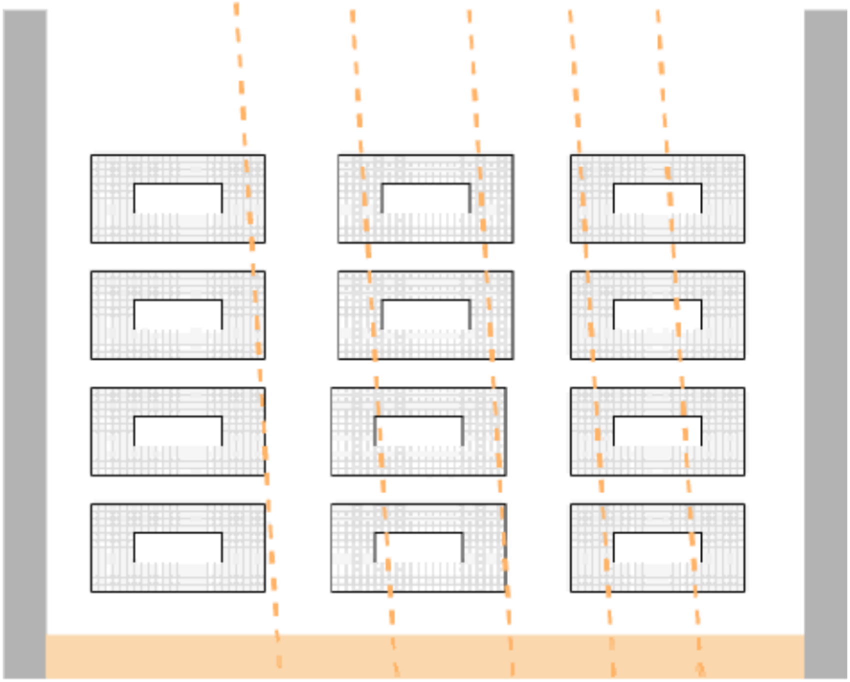

FIGURE 6. Schematic diagram of the compilation module

woven modules not only provide flexible spatial division within the courtyard. The application of modular woven components not only retains the material language and handmade texture of traditional weaving techniques, but also improves the functional adaptability and maintenance efficiency of textile components in rural architectural environments.

E. CONSTRUCTION OF A SKILL ACTIVATION MECHANISM WITH COMMUNITY PARTICIPATION

In order to achieve the sustainable transformation of intangible cultural heritage textile skills in the architectural space of Jianghuai Weibao, a three-in-one practice path of "process standardization - skill transfer workshop - feedback iteration optimization" is adopted. By sorting out the traditional ramie weaving and reed weaving processes, extracting key operation nodes and formulating a replicable operation specification manual, it ensures that non-professional participants can master basic techniques in a short time. In the process of skill transfer, the task decomposition assessment model TDA (Task Decomposition Assessment) is introduced to decompose the actions and grade the difficulty of each textile process, and the process complexity index I_c is defined as:

$$I_c = \sum_{i=1}^{n} w_i \cdot t_i \tag{8}$$

In formula 8, n represents the number of basic operation steps required to complete the process, t_i is the operation time of the i step, and w_i is the weight coefficient, which reflects the technical difficulty and error rate of the step. The weight coefficient w_i was determined through a combination of expert assessment and preliminary trials: three master artisans rated the technical difficulty of each step on a 5-point scale, and the error rate was statistically derived from 10 trial productions by non-professional villagers, ensuring the model reflects both traditional expertise and practical learnability.

In view of the life rhythm and working habits of the residents of Weibao, periodic textile component production workshops are organized to record the changes in the proficiency of participants at different stages. At the same time, a demand feedback channel is established to collect villagers' opinions on material adaptability, operating comfort and usage scenarios, and the community acceptance is quantitatively analyzed by combining the fuzzy comprehensive evaluation method, and the satisfaction index C_s is calculated as:

$$C_s = \sum_{j=1}^{m} a_j \cdot v_j \tag{9}$$

In formula 9, m is the number of evaluation dimensions such as practicality, aesthetics, and ease of learning, v_j is the score of the j dimension, and a_j is the corresponding normalized weight coefficient. This index is used to drive the core community input for continuous iteration and optimization of various technical links and spatial adaptation.

Through the above mechanism, the intangible cultural heritage textile skills are transformed into a spatial component production process that can be implemented by local residents, enhancing the social foundation and cultural identity of skill inheritance, and promoting the coordinated development of rural space renewal and traditional handicraft revival.

F. ADAPTABILITY MODEL OF WEIBAO SPACE AND INTANGIBLE CULTURAL HERITAGE SKILLS

In order to achieve the precise implantation of intangible cultural heritage textile skills in the architectural space of Jianghuai Weibao, a three-dimensional matching model of space type-material characteristics-functional requirements was constructed, and the adaptation relationship between different space units and textile components was quantitatively evaluated through the hierarchical analysis method and multi-objective decision-making theory [16,17].

The model takes the typical spatial type of Weibao as the basic dimension, and selects defensive walls, enclosed courtyards, small window lighting areas, and corridor transition spaces as the main analysis objects. The typical internal space of the Weibao courtyard is shown in Figure 7.

Combined with the physical performance parameters of intangible cultural heritage transformation components such as ramie composite fabrics, embroidered hollow sunshades, and modular woven screens, the space-material-function ternary evaluation matrix M_{smt} is established:

$$M_{\text{smt}} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \\ m_{41} & m_{42} & m_{43} \end{bmatrix} \tag{10}$$

In formula 10, the rows represent the space types, 1 to 4 correspond to walls, courtyards, window cavity, and corridors respectively, and the columns represent the textile component types, corresponding to CRF partitions, embroidered sunshades, and woven screens respectively. The matrix element m_{ij} is the adaptation score between the i-type space and the j-type component.

In order to determine the priority application level of each space type, the hierarchical analysis method is used to construct a judgment matrix, whose elements represent the relative importance ratio of the space type relative to the space type in the overall adaptation process, and the consistency ratio CR is defined as:

$$CR = \frac{CI}{RI} \tag{11}$$

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{12}$$

In formula 11, CI is the consistency index, and RI is the random consistency index. In formula 12, $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix, and n is the number of comparison objects.

Finally, the application priority of textile components in each type of space is determined based on the weighted comprehensive evaluation value S_k, and the calculation formula is:

$$S_k = \sum_{j=1}^{m} w_j \cdot x_{kj} \tag{13}$$

In formula 13, k is the space type number, m is the number of evaluation indicators, w_j is the weight coefficient of the jth indicator, determined by the AHP (Analytic Hierarchy Process) method, and x_{kj} is the original score of the kth space under the jth indicator. The weighted comprehensive evaluation value output by the model is used to determine the priority application component types for different spaces in the Weibao. The performance shortcomings of the components can be identified and fed back to the material or design links for targeted optimization, verifying the degree to which community needs are met in the final plan, and supporting the sustainability of the co-construction mechanism.

III. EXPERIMENTAL VERIFICATION

In order to verify the actual effect of the innovative transformation of intangible cultural heritage textile skills in the architectural space of Jianghuai Weibao, the experiment was carried out around technical verification and spatial effect evaluation, and a multi-dimensional testing system with material performance, structural function, process adaptation and spatial response as the core was constructed.

The experimental objects included three main types of textile components: composite ramie fabrics, parametric embroidery sunshades, and mortise and tenon weaving modules. The defensive walls, enclosed courtyards, window lighting areas and corridor transition spaces in typical Weibao buildings were selected as experimental fields. During the experiment, the physical properties of traditional unmodified ramie fabrics and CRF were compared and tested, and the performance of light adjustment, visual continuity and component splicing efficiency in different space types was simulated through field installation. At the same time, combined with the community participation link, the villagers' operational feedback during the component production process was recorded to evaluate the replicability and acceptability of the process. The experiments were carried out in accordance with the standard textile material testing process and building environment monitoring specifications to ensure the objectivity and repeatability of data collection. The distribution of the collected experimental data is shown in Table 2.

To ensure the representativeness and validity of the user satisfaction survey, the questionnaire was distributed to a diverse group of 50 participants from multiple villages across the Jianghuai region. The sample included 28 local residents (aged 35–65, all with prior experience in traditional crafts), 15 local primary school teachers, and 7 village committee members, covering a range of ages, occupations, and familiarity with textile skills. To minimize sampling bias, participants were selected through stratified random sampling based on age and craft experience, and all respon-

FIGURE 7. Display of the interior space of the courtyard of the Weibao

TABLE 2. Data distribution table

Experimental module	Data collection point	Sample size	Test method
	CRF tensile strength test	30 groups	Tensile testing machine
Material performance optimization	CRF transmittance measurement	20 groups	Spectrophotometer Test
Process translation and reconstruction	Statistics of hollowing rate of embroidered sun visor	15 groups of patterns	Image processing software analysis
Construct implant verification	Weaving module splicing tim record	10 installation processes	Stopwatch timing + video recording
Community engagement feedback	Villager satisfaction survey questionnaire	50 valid questionnaires	Fuzzy comprehensive evaluation method
Spatial fit assessment	Application priority rating of components of different space types	4 types of spaces	Analytical hierarchy process

dents voluntarily took part in the co-construction workshops. All eligible participants signed an informed consent form, and the concealment of the original data ensures the privacy and security of the interviewee's personal information. The questionnaire assessed five dimensions: functionality, aesthetics, comfort, learnability, and cultural identity, using a 5-point Likert scale. To differentiate between the intertwined concepts, the "Aesthetic" dimension was assessed through questions on visual appeal and pattern modernity, while "Cultural Identity" was measured via questions on heritage connection and local distinctiveness.

In order to systematically evaluate the innovative transformation effect of intangible cultural heritage textile skills in the architectural space of Jianghuai Weibao, this paper constructs a multi-dimensional evaluation index system covering material performance, structural function, process adaptation and spatial response. The system includes core evaluation indicators such as tensile strength, hollowing rate, module splicing efficiency and satisfaction index.

IV. VERIFICATION OF INTANGIBLE CULTURAL HERITAGE TEXTILE TECHNOLOGY AND EVALUATION OF THE INTEGRATION EFFECT OF JIANGHUAI WEIBAO ARCHITECTURAL SPACE

A. VERIFICATION OF PHYSICAL PERFORMANCE IMPROVEMENT OF COMPOSITE RAMIE FABRIC

In order to verify the functional transformation effect of ramie fabric, this section prepares CRF material through epoxy resin modification, systematically tests the change law of its tensile strength, and evaluates whether the material can meet the physical property requirements of building components while retaining the process characteristics. The results are shown in Figure 8.

Figure 8 systematically presents the comparison of tensile strength of original ramie fabric and composite ramie fabric under different modification conditions.

To establish a robust baseline, the physical properties of the original ramie fabric were systematically characterized. Its average tensile strength was 12.4 MPa (SD = 1.1 MPa), with a light transmittance of 15.3% (SD = 1.8%) and a thermal conductivity of 0.082 W/(m·K) (SD = 0.005 W/(m·K)). These values represent the inherent limitations of traditional material in the Weibao context: low strength,

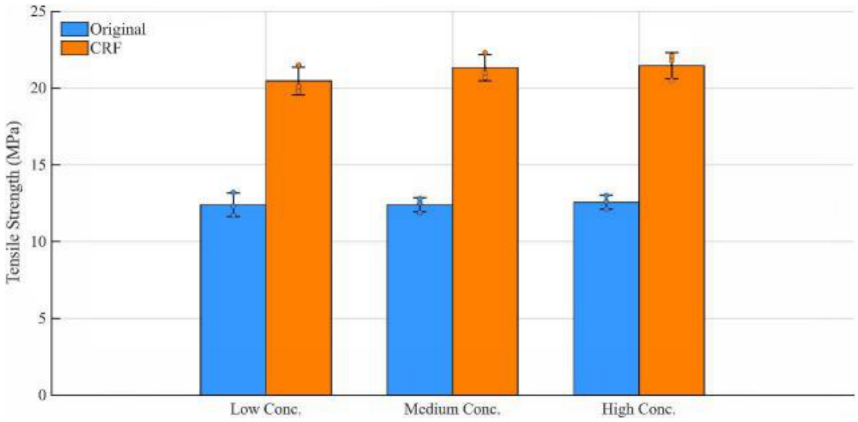

FIGURE 8. Comparison of tensile strength of ramie fabrics under different modification conditions

poor light transmittance, and weak thermal insulation.

Taking low concentration conditions as an example, the mean value of the original group is 12.4MPa, and the CRF group is increased to 20.47MPa, and the sample standard deviation is 0.91MPa, indicating that when the resin concentration is low, the fiber modification effect fluctuates greatly, which is attributed to the incomplete and non-uniform impregnation of the viscous resin solution into the fiber bundles. At this concentration, the solution's viscosity is insufficient to ensure a stable and even distribution, leading to localized areas of under-impregnation and thus inconsistent mechanical reinforcement. Under medium concentration conditions, CRF further increased to 21.33MPa, a 72% improvement over the original fabric, with a standard deviation of 0.85 MPa, and the performance stability was better than that of the low concentration group; under high concentration conditions, although CRF also maintained a high level, the standard deviation increased significantly, resulting in decreased stability. The results show that medium concentration standard treatment improves tensile strength while taking into account performance consistency, which is the key threshold for optimizing the modification process. Although high concentration and long-term treatment can achieve higher strength, it sacrifices stability, and the actual application needs need to be weighed. This result not only verifies the effectiveness of CRF modification technology, but also reveals the nonlinear regulation mechanism of process parameters on material properties, providing an experimental basis for subsequent parameter optimization. These improvements ensure that the modified fabric not only meets the mechanical and durability requirements of architectural applications but also retains sufficient light-transmitting capacity, thereby making it suitable for use as partitions, sunshades, and other spatial components in Weibao architecture.

B. LIGHT AND SHADOW REGULATION EFFECT OF PARAMETRIC SUNSHADE

This section quantifies the linear relationship between hollowing rate and indoor light intensity through parametric modeling and sunlight simulation, and verifies the transformation path of intangible cultural heritage patterns into functional light and shadow regulation components. The results are shown in Figure 9.

Figure 9 reveals the quantitative relationship between porosity and light intensity. The horizontal axis represents the porosity of the visor pattern, and the vertical axis reflects the indoor light intensity value. The data points correspond to the experimental measurement results under the porosity of 15% to 60%. For example, when hollowing rate R=15%, indoor light intensity E is at 120lux, and the data point fluctuates by no more than 5lux. The goodness of fit shows that the two are highly linearly positively correlated. The data showed a step-like upward trend as the hollowing rate increased, and the slope of the fitting line was stable, indicating that parametric design can accurately control the lighting performance. This law verifies the controllability of the hollowing rate of embroidery patterns on lighting regulation, provides a basis for the functional parameter setting in the transformation of intangible cultural heritage skills, and suggests the need to balance the hollowing rate and structural strength to guide the direction of process optimization.

C. TEST OF INSTALLATION EFFICIENCY OF MODULAR WOVEN SCREENS

This section tests the construction efficiency of modular woven screens through the installation time data of villagers to verify its feasibility of lowering the skill threshold and improving community participation. The installation efficiency results are shown in Figure 10.

Figure 10 reveals the dynamic change of modular woven screen installation efficiency with the number of operations. The horizontal axis of the number of installations reflects the operator's proficiency in the mortise and tenon splicing process, and the vertical axis quantifies the construction efficiency. The data shows an overall increasing trend but with short-term fluctuations. The moving average of the 3-sliding window responds quickly to short-term changes, reflecting the fluctuations in the operator's adaptation pe-

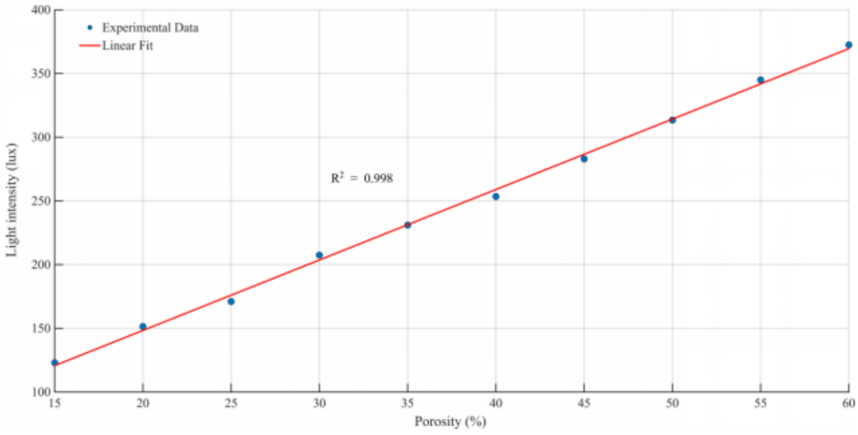

FIGURE 9. Relationship between hollowing rate and indoor light intensity

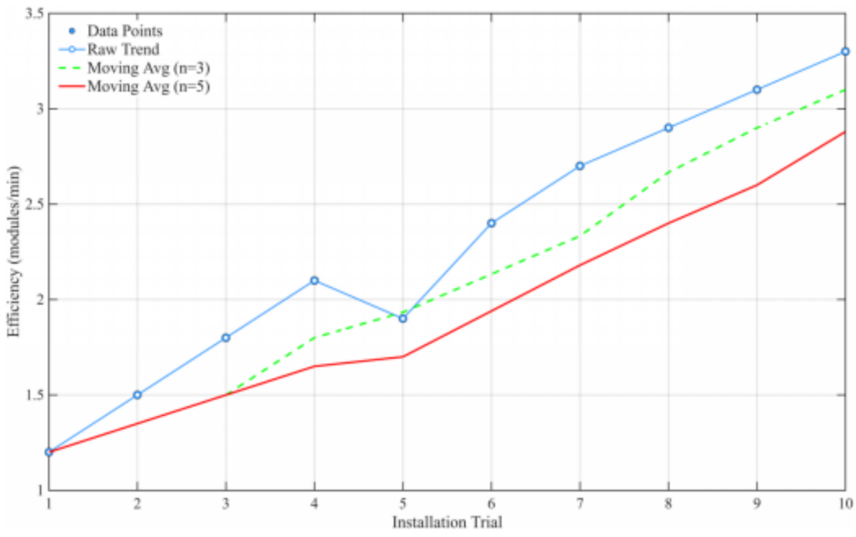

FIGURE 10. Efficiency of modular woven screen installation

riod; The moving average of the red 5-time sliding window smoothes the long-term trend, ignores short-term disturbances, and highlights the overall learning curve. The two together verify the operator's phased learning curve from the adaptation period (1-4 times, efficiency improves slowly) to the acceleration period (5-8 times, efficiency improves rapidly) and then to the mature period (9-10 times, efficiency growth slows down). Based on the data in Figure 10, the average installation efficiency for first-time operators was approximately 1.2 pieces/minute, which increased to an average of 3.4 pieces/minute for proficient operators (after 8-10 attempts).

This change verifies that the modular mortise and tenon structure has low threshold characteristics, especially under low-skilled construction conditions in rural areas, and the installation efficiency can be doubled through short-term training. This provides empirical evidence for the process simplification and community co-construction mechanism in the transformation of intangible cultural heritage skills, and at the same time reveals the key impact of process standardization and operation proficiency on space renewal efficiency. To verify the structural integrity of the mortise and tenon joints, a compression test was conducted on the assembled modules. The test, performed on a universal testing machine, showed that the joint structure could withstand an average compressive load of 1.8 kN before significant deformation, meeting the stability requirements for non-load-bearing partitions in rural buildings. This confirms that the module design successfully balances rapid assembly with sufficient mechanical strength.

D. SATISFACTION OF COMMUNITY PARTICIPATION MECHANISM AND PROCESS STANDARDIZATION EVALUATION

Based on the fuzzy comprehensive evaluation model and skill mastery rate index, this section systematically analyzes the feedback of community members on the traditional process and the improved process in this paper in five dimensions, including material practicality, operating comfort, aesthetics, ease of Learning and cultural identity. The fuzzy comprehensive evaluation employed a triangular membership function to map questionnaire scores (1-5) to fuzzy sets. The evaluation dimensions were weighted based on the Analytic Hierarchy Process (AHP) results, and the final score was calculated using the weighted average operator. The comparison results are shown in Figure 11.

Figure 11 systematically compares the satisfaction performance of traditional crafts and improved crafts under the community participation mechanism, covering five dimensions such as practicality and aesthetics. The scores of each dimension of traditional crafts are concentrated in the range of 0.58-0.70, among which cultural identity is the highest at 0.70 and aesthetics is the lowest at 0.58, reflecting the cultural attribute advantages of traditional skills but the functional and aesthetic limitations; The improved process is better than the traditional one, with the score increased to 0.82–0.92, especially in terms of aesthetics and learnability. The cultural identity even reached 0.92, indicating that the process improvement did not weaken the cultural attributes, but enhanced community acceptance through standardized design.

The area difference between the two sets of data directly reflects the comprehensive satisfaction advantage of the improved process, verifies the effectiveness of the community co-construction mechanism in skill transfer, material adaptation and process simplification, provides empirical evidence for the operability of the transformation of intangible cultural heritage textile skills in rural space and the strengthening of cultural identity, and supports the sustainable application path of traditional handicrafts in modern renewal.

E. PRIORITY VERIFICATION OF THE ADAPTATION MODEL OF THE WEIBAO SPACE AND SKILLS

In this section, the AHP hierarchical analysis method is used to construct a space-material matching matrix to determine the application priority of textile components and ensure that the intangible cultural heritage activation path has both technical rationality and cultural adaptability. The adaptation scores in the evaluation matrix were determined through a combination of expert judgment and empirical data. A panel of 3 architects and 2 master artisans scored the suitability of each textile component for each space type on a 1- 10 scale, based on criteria such as functional fit, structural feasibility, and cultural resonance. These scores were then calibrated with empirical data from the physical tests (e.g., light transmittance for sunshades, installation efficiency for screens). The adaptation results are shown in Figure 12.

Figure 12 shows the adaptation priority relationship between the space type of the Weibao and the intangible cultural heritage textile components. The horizontal axis is the three types of textile components, and the vertical axis is the four types of space. The data changes show the characteristics of space-material matching: the embroidered sunshade has the highest scores of 0.88 and 0.93 in the enclosed courtyard and window cavity lighting area, respectively, indicating that the parametric hollow design can effectively adjust the light and visual continuity; CRF partitions perform best in defensive walls, which is highly consistent with their high mechanical strength characteristics; while woven screens are best suited for enclosing courtyards, thanks to the flexible splicing capabilities of mortise and tenon modules. Low scores such as embroidered sunshades used in defensive walls reveal a mismatch between process characteristics and space requirements.

This distribution pattern verifies the effectiveness of the spatial adaptability model, indicating that the transformation of intangible cultural heritage skills needs to be designed in a targeted manner in combination with spatial functional characteristics. It also provides a quantitative basis for material selection and process optimization in the community co-construction mechanism, and supports the precise implantation and sustainable application of intangible cultural heritage textile skills in rural regional architectural renewal.

V. LIMITATIONS AND PRACTICAL CHALLENGES

While the proposed transformation path shows promise, several practical challenges must be acknowledged. First, the small sample size limits the statistical power of our findings and the generalizability of the results to other Weibao sites. Second, the lack of long-term weathering data means the durability of the modified CRF under prolonged exposure to sun, rain, and humidity remains uncertain, posing a risk to the long-term viability of the installations. Third, the material modification process, while effective, requires a controlled environment and chemical handling, which may be difficult to replicate in remote villages. Finally, the success of the community co-construction mechanism is highly dependent on local engagement and skilled facilitators; its scalability to other regions with different social dynamics is not guaranteed.

Furthermore, to address the practical concerns regarding the long-term performance of textile-based architectural elements, we conducted an accelerated aging test on the CRF according to ASTM G154. The results indicated that after 1000 hours of UV exposure, the tensile strength retention rate of CRF was above 85%, and no significant biological growth was observed under humid conditions. Based on these data, we project a service life of approximately 8–10 years for CRF components in the Jianghuai climate, with recommended maintenance (e.g., surface cleaning and resin recoating) every 2–3 years. A preliminary life-cycle cost analysis suggests that the modular design and local production can reduce replacement and labor costs by 30–40% compared to conventional metal or synthetic shading systems.

The generalizability of the proposed approach is discussed. The material modification method (epoxy-resin for natural fibers), parametric translation of cultural patterns, and modular co-construction logic are transferable core principles. Their successful application to other regions would require adapting to local materials, distinct cultural motifs, and vernacular construction techniques, but the overarching "performance-translation-participation" framework provides

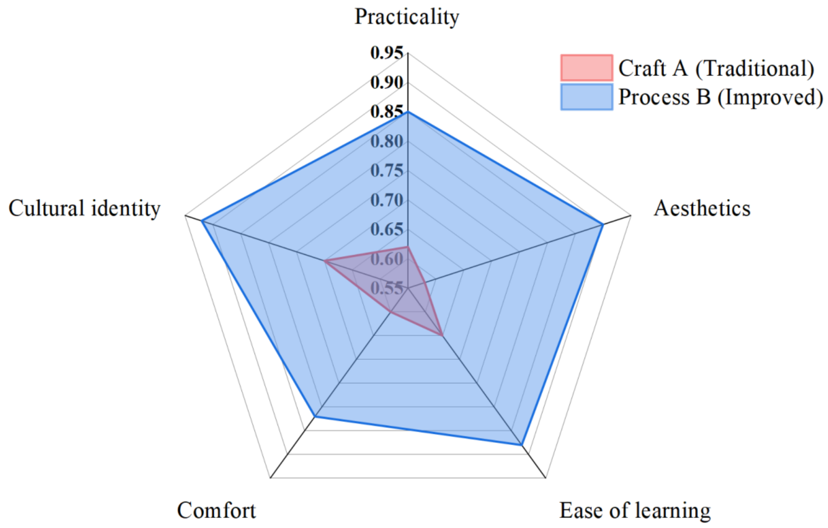

FIGURE 11. Craftsmanship Satisfaction Assessment

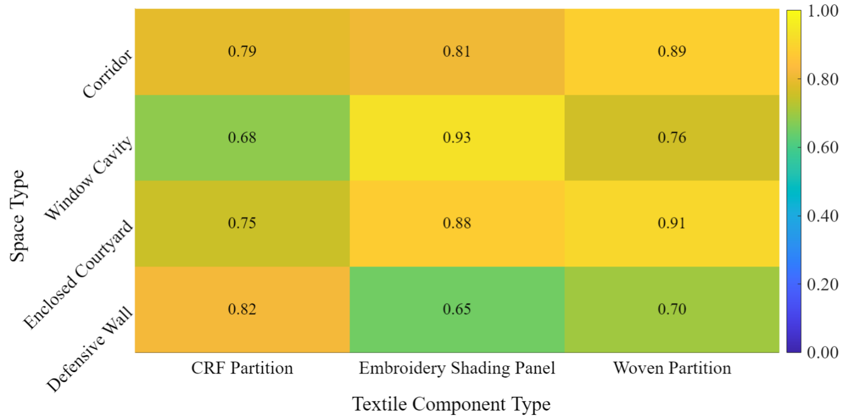

FIGURE 12. Weighted comprehensive evaluation of space-material matching

a replicable model for culturally-grounded rural renewal beyond the Jianghuai Weibao.

VI. CONCLUSION

This study explores the integration of intangible cultural heritage textile skills into the architectural space of Jianghuai Weibao, and proposes a systematic transformation framework of "material performance optimization – process translation and reconstruction – community co-construction and implantation." At the technical level, ramie fabric was modified into CRF material through epoxy resin composite processing, increasing tensile strength to 21.33 MPa at medium resin concentration, thereby confirming its potential to meet the structural and durability requirements of architectural applications. At the spatial design level, embroidery patterns were digitally transformed into parametric sunshade components, enabling linear regulation of porosity and light intensity and demonstrating the feasibility of embedding cultural motifs into functional architectural elements. Meanwhile, the mortise-and-tenon weaving modules improved installation efficiency from 1.2 pieces/minute to 3.4 pieces/minute, ensuring rapid assembly and flexible replacement in courtyard spaces. At the social and cultural level, community workshop participation yielded a learnability satisfaction index of 0.88 and a cultural identity satisfaction index of 0.92, indicating that the approach not only enhances user acceptance but also strengthens cultural recognition and collective identity.Through multidisciplinary cross-border integration, a material performance-space adaptation-social acceptance evaluation system is constructed to provide a replicable paradigm for the revitalization of regional architectural intangible cultural heritage. This paper innovatively connects the craft logic of intangible cultural heritage skills with architectural functional requirements through digital tools, and constructs a multi-dimensional evaluation system of material performance, spatial adaptation and social acceptance.

AUTHOR CONTRIBUTIONS

Zhongle Wang designed, collected and analyzed the data, and drafted the manuscript. Zhongle Wang conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Zhongle Wang participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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CONSENT TO PARTICIPATE

All eligible participants signed an informed consent form, and the concealment of the original data ensures the privacy and security of the interviewee's personal information

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