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Research on the Design of Zhuang Brocade Patterns Based on Automatic Pattern Generation

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Abstract: To promote the inheritance of Zhuang brocade culture and the rapid extraction of features and automatic generation of patterns, this paper constructs a feature dataset of Zhuang brocade patterns and proposes an automatic generation technology using relative coordinates and regional content replacement. Firstly, by sorting through a large number of cases, a feature dataset of Zhuang brocade patterns is constructed. For the significant features of Zhuang brocade patterns, intelligent extraction algorithms and processes are used to effectively extract the color matching, patterns, and organizational forms of the patterns into the feature dataset. Secondly, to generate Zhuang brocade patterns quickly, an automatic generation technology based on genotype encoding and regional replacement algorithms is proposed, which encodes these pattern elements into a format that can be interpreted by computer algorithms. Finally, through similarity evaluation, the method's feasibility for rapid extraction and generation of Zhuang brocade patterns is effectively verified. This method is significant for the inheritance of Zhuang brocade patterns and the development of the intangible cultural heritage industry.

Keywords: Zhuang brocade; pattern design; intelligent extraction; automatic generation

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1. Introduction

Zhuang brocade is a traditional hand-woven fabric with distinctive characteristics of the Zhuang ethnic group in China and is one of the excellent intangible cultural heritages of China with a long history [1]. In the context of the multicultural and information-rich era, the issue of inheriting and innovating Zhuang brocade urgently needs to be addressed. For instance, there are challenges such as the difficulty in innovating brocade patterns, the singularity of application forms, and the struggle to inherit and develop.

Patterns are important parts of Zhuang brocade, with diverse patterns and distinctive organizational forms. However, the current methods of pattern extraction primarily rely on perceptual cognition and manual drawing, lacking efficiency and precision. This is not conducive to the inheritance and promotion of Zhuang brocade as an intangible cultural heritage. To improve work efficiency, it is necessary to use computers and modern information processing technology to replace manual work in extracting pattern features [2]. Introducing digitalization techniques to Zhuang brocade allows for the accurate extraction of pattern features by transforming traditional patterns into digital ones. It not only enables the digital preservation of the characteristics of Zhuang brocade patterns but also facilitates the inheritance and protection of intangible cultural heritage.

Scholars have applied computer technology methods such as automatic pattern generation, big data mining, and 3D printing to the design of intangible cultural heritage products. This has provided insights and references for addressing the issues of inheriting and innovating Zhuang brocade patterns. For example, Tian et al. [3] proposed an automatic generation system for batik pattern design, which is conducive to the dissemination and promotion of intangible culture such as batik. Jia et al. [4] proposed an element extraction and classification method based on an intelligent convolutional neural network (CNN) to

realize traditional pattern innovation using modern technology. Jiang et al. [5] utilized crawlers, algorithmic computing, and other means, based on big data mining, to extract and utilize the cultural elements of Pearl S. Buck. Liang [6] developed egg-carving cultural creative products based on the 3D printing technological innovation of the Internet of Things. From this perspective, combining heritage product pattern design with computer tech, notably auto-pattern generation, is key to innovation and inheritance and solving traditional design bottlenecks.

Based on the above research background, this article focuses on the study of Zhuang brocade pattern design, specifically examining the features of color schemes, patterns, and organizational forms. It proposes a method for automatic pattern generation based on relative coordinates and regional content replacement. The research results realize the rapid generation of Zhuang brocade patterns and solve the problem of difficult pattern innovation. Furthermore, it also promotes the integration of Zhuang brocade patterns into practical applications, which plays an important role in the innovative inheritance of Chinese Zhuang brocade and the development of the non-heritage industry.

The structure of this paper is as follows. The Section 2 briefly introduces the research status of the theory on automatic pattern generation technology and the extraction of pattern color, pattern, and organizational characteristics. The Section 3 constructs a feature dataset for Zhuang brocade patterns and designs algorithms for the extraction of pattern color, pattern, and organizational characteristics. In the Section 4, the extracted pattern colors, patterns, and organizational characteristics are encoded, the rapid automatic generation of patterns is achieved through regional replacement algorithms, and a similarity evaluation of Zhuang brocade patterns is conducted. Finally, in the Section 5, conclusions are drawn, shortcomings are pointed out, and directions for future improvements are suggested.

2. Related Literature and Work

This section analyzes the current state of research on automatic pattern generation technology and the extraction theory of pattern color, pattern, and organizational characteristics.

2.1. Automatic Pattern Generation Technology

The automatic pattern generation technology of Zhuang brocade patterns mainly contains the steps of pattern element extraction and generation algorithm research.

The extraction of pattern elements is the basis for pattern reconstruction and rapid generation. Scholars have further completed the exploration of rapid generation applications by classifying and extracting pattern elements. Convolutional neural networks (CNNs) extract key features for classifying indigo textiles [4], quantitative aesthetics categorize Persian carpets [7], and the Canny method detects cryptogamic plant outlines [8]. The research also includes image segmentation algorithms for pattern redesign [9] and the automated extraction of silhouette costume patterns [10].

After feature extraction, math functions and computer languages are used for autogen algorithms. AGPG models generate multi-purpose camouflage patterns [11], IFS and curve functions simulate floral patterns [3], and color transfer methods create colored mandalas [12]. Adversarial networks and aesthetics guide auto-gen pattern design [13].

2.2. Works Related to the Pattern Color Extraction Algorithm

Common color extraction theories include threshold, color model, clustering, and ML-based methods. Clustering algorithms, which are suitable for multi-color extraction in this study, are used to group colors by similarity. This article primarily uses K-means clustering to extract colors from Zhuang brocade, segmenting the image into clustered blocks to extract representative colors for segmentation and primary color retrieval. For example, k-means++ and Canny operator-based smart recognition extract and redesign colors [14]. The P-ASK framework, using K-means, extracts primary colors from artifacts [15]. K-means clustering is used for porcelain primary color extraction in fashion design [16]. K-means' evolution enhances Chinese traditional culture research and application. As a key

feature of Zhuang brocade, its color scheme is precisely extracted via K-means for design and application resources.

2.3. Works Related to Pattern Extraction Algorithms

In Zhuang brocade pattern extraction, three main algorithms are used for segmentation, noise reduction, and contour extraction. GrabCut segments the image, the Relative Total Variation (RTV) algorithm extracts the target pattern, and binarization separates the target from the background.

Multiple algorithms exist for image segmentation and decomposition, but GrabCut is favored for textiles with intricate textures. Scholars have enhanced GrabCut for more precise pattern extraction. The improvements include integrating segmentation with multi-scale feature extraction [17], combining color correction with interactive GrabCut for efficiency [18], and merging deep image processing with object segmentation and model building [19]. GrabCut effectively extracts features of Zhuang brocade patterns, with interactive algorithms compensating for detail omissions in the extraction process.

Image smoothing is essential for computer vision and graphics applications [20]. The RTV algorithm removes image details to extract main patterns. Zhuang brocade, made manually with tools like bamboo looms using a continuous warp and discontinuous weft method, can have irregular color errors and uneven textures due to inconsistent manual effort or machinery. This makes extracting clear pattern contours challenging. The RTV model's variation algorithm differentiates stable main structures from noise textures [21], effectively separating them in Zhuang brocade patterns.

Binarization, which is key to distinguishing image foregrounds and backgrounds [22], converts digital images to black and white while retaining essential attributes [23]. Multi-level thresholding in grayscale images, used for enhancement and segmentation, involves various criteria for selecting threshold values, including the Otsu criterion, which maximizes inter-class variance [24]. This method is particularly effective for segmenting Zhuang brocade patterns with distinct color differences between patterns and textures.

2.4. Works Related to Pattern Organization Form Extraction

Shape grammar facilitates the serialization of complex two-dimensional and three-dimensional designs [25], so this article uses it for the extraction and reuse of pattern organization forms. It has been improved for use in Miao fabric pattern design [26], enabling the reuse of personalized batik patterns [27] and the design of clothing with shadow puppet characteristics [28]. In the process of extracting Zhuang brocade patterns, shape grammar is applied to reconstruct the design approach, deduce the composition rules, extract the minimal units, and accurately depict the complete patterns to capture their characteristics.

Current algorithms cannot accurately design patterns that match Zhuang brocade's unique composition, prompting a new extraction and auto-generation algorithm. This article is divided into three parts. First, it uses suitable algorithms to segment and accurately extract pattern features. Second, it constructs an auto-generation process for various similar-styled pattern designs based on pattern composition. Finally, it evaluates the feasibility of the algorithm through case presentations and style similarity assessments.

3. Construction of the Feature Dataset of Zhuang Brocade Patterns and Design of the Extraction Algorithm

This section systematically collects and selects representative Zhuang brocade patterns and analyzes pattern features. The characteristics of Zhuang brocade patterns are mainly composed of pattern color, pattern, and organizational form. A feature dataset for Zhuang brocade patterns is constructed, and an algorithm design for the extraction of Zhuang brocade pattern features is carried out.

3.1. Feature Dataset Construction

To address the extensive workload resulting from the diverse patterns of Zhuang brocade, it is beneficial to establish a Zhuang brocade pattern features dataset. After analyzing a large number of cases, it can be concluded that the pattern features of Zhuang brocade consist of the following three main components: color, pattern, and organizational form. These components represent the cultural characteristics of Zhuang brocade. The color scheme of Zhuang brocade patterns predominantly features heavy colors with other hues as secondary elements. The motifs often carry symbolic meanings, based on geometric patterns with floral, avian, fish, and insect motifs as derived characteristics. In terms of organization, the patterns are intricately arranged with a clear sense of density and layering, exhibiting a discernible regularity. Structurally, they often employ geometric patterns of two-dimensional and four-dimensional continuity as the fundamental framework.

As shown in Figure 1, this section organizes representative keywords based on the characteristics of Zhuang brocade pattern colors, motifs, and organizational forms. Building upon the features of Zhuang brocade patterns and the associated keywords, it aims to enhance the efficiency of selection and effectively identify images with high representativeness, accurately preserving the characteristics of Zhuang brocade patterns.

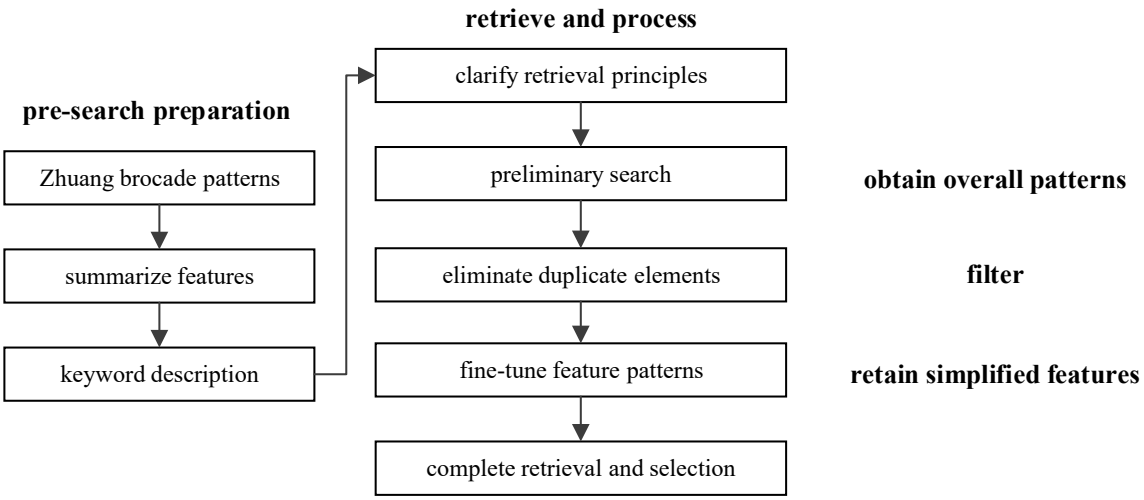


Figure 1. Flowchart showing the collection of the Zhuang brocade dataset.

The overall style of a Zhuang brocade pattern is divided into two main styles as follows: contrasting and harmonious. Color characteristics are primarily related to the weaving technique of Zhuang brocade, which involves discontinuous warp and weft. The warp threads provide the background color, while the weft threads use color blocks to form the pattern's content and color features. These color features include both the organizational form colors and the motif colors.

Because of the complexity of colors in Zhuang brocade, three categories of labels were preset in advance to achieve color matching and design. These are "Similar Color Scheme", "Contrasting Color Scheme", and "Other Color Schemes". Then, professionals were invited to classify the collected Zhuang brocade patterns with the above three types of labels. After the classification session, typical cases were selected for each labeled group, forming a dataset of typical features of Zhuang brocade pattern colors, as shown in Figure 2.

There are many kinds of patterns in Zhuang brocade, with geometric patterns being the majority. Geometric patterns, botanical patterns, animal patterns, and text patterns are the more typical pattern patterns in Zhuang brocade. This article used the names of motifs as keywords for search and retrieval. Through collection, screening, and organization, it identified 25 types of Zhuang brocade motifs. The most intuitive and clear motifs from these 25 types were selected and cut, including geometric, plant, animal, and text pat-

terns, totaling 27 types. Ultimately, a motif extraction dataset was established, as shown in Figure 3.

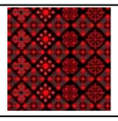
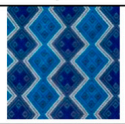
Sample and number of color extraction of Zhuang brocade					
					
C1	C2	C3	C4	C5	C6
					
C7	C8	C9	C10	C11	C12
					
C13	C14	C15	C16	C17	C18

Figure 2. Dataset of color feature extraction of Zhuang brocade pattern.

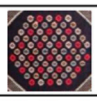
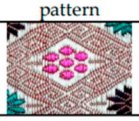
A–Geometric patterns		B–Plant patterns	C–Animal patterns	D–Text patterns
				
A01–Circular pattern	A08–Swastika pattern	B01–Floral pattern	C01–Bird pattern	D01–"Fu" character pattern
				
A02–Cloud and thunder pattern	A09–Water ripple pattern	B02–Flower and tree pattern	C02–Bird pattern	D02–"Shou" character pattern 1
				
A03–Wansheng pattern	A10–Sun pattern	B03–Chrysanthemum pattern	C03–Fish pattern	D03–"Shou" character pattern 2
				
A04–Panchang pattern		B04–Plum blossom pattern	C04–Frog pattern	D04–"Shou" character pattern 3
				
A05–Persimmon calyx pattern		B05–Osmanthus flower pattern	C05–Lion pattern	D05–"Xi" character pattern
A06–Large well character pattern			C06–Chicken pattern	
A07–Small well character pattern			C07–Butterfly pattern.	

Figure 3. Dataset of feature extraction of Zhuang brocade pattern motifs.

Zhuang brocade patterns mainly weave bipartite and quadripartite continuous geometric patterns on the plain pattern, forming continuous geometric patterns and a very distinctive organizational form style. This article mainly considered the organizational form of Zhuang brocade with a basic composition of geometric elements, taking bipartite and quadripartite continuity as the research object. Extensions and adjustments were made on this basis. Similarly, the dataset of pattern organizational forms was also constructed by collecting, screening, and organizing numerous samples, as shown in Figure 4.

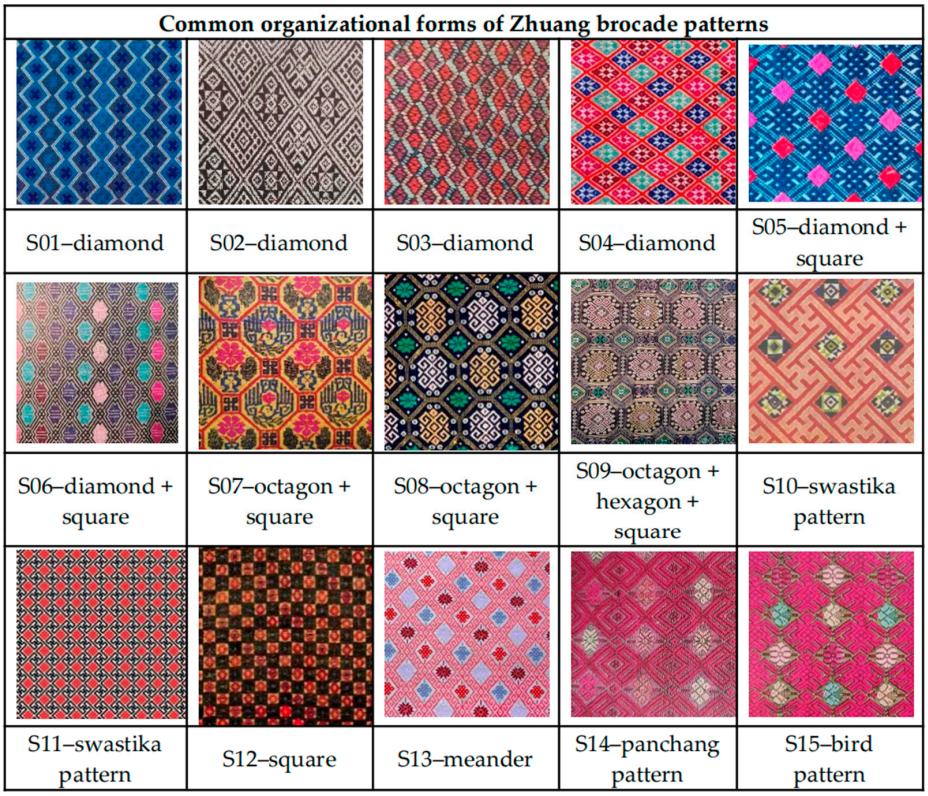


Figure 4. Feature extraction dataset of Zhuang brocade pattern organization form.

3.2. Color Feature Extraction Algorithm Design and Results

As shown in Figure 5, in the process of color extraction, taking any sample as an example, the algorithm implementation approach involves inputting the selected image into the K-means algorithm to extract the primary colors' hexadecimal codes and their proportions. Then, it matches the closest colors from the color dictionary and creates a proportion diagram.

The process is mainly divided into the following steps:

1. Step 1: input the image and the number of clusters (the number of extracted colors).

Randomly select an image from the Zhuang brocade color scheme extraction dataset, such as image C (11).jpg shown in Figure 6. Before initiating the main function, create an ArgumentParser() object to accept command-line arguments. Establish the corresponding variables to receive the values of these arguments, retaining two "optional" command-line arguments as follows: clusters and imagepath.

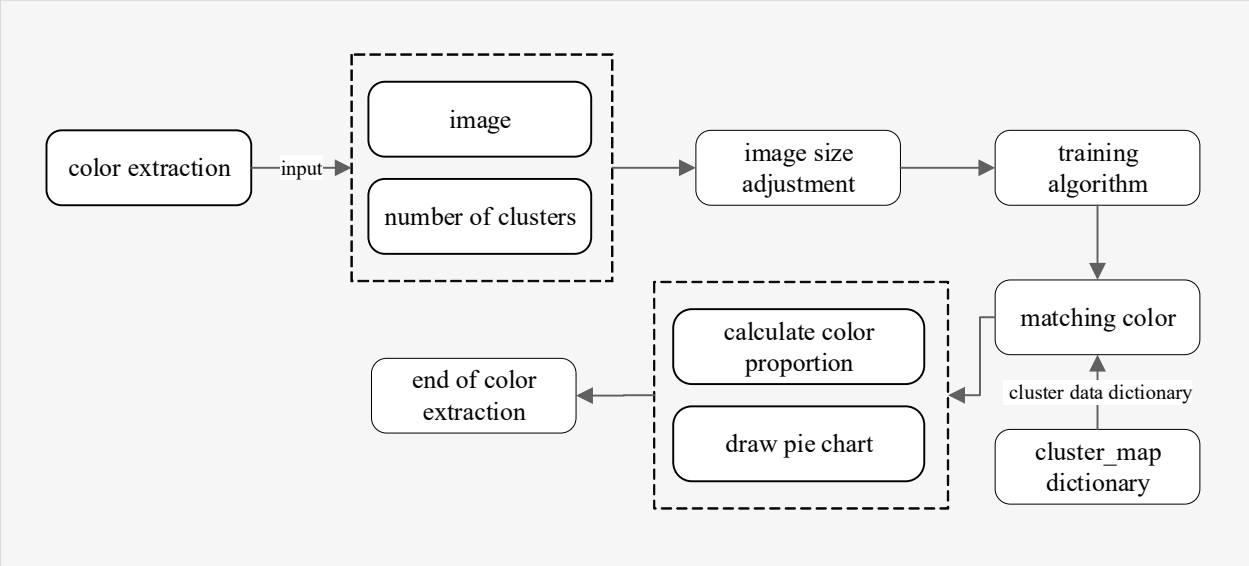


Figure 5. Flowchart of color feature extraction from Zhuang brocade.



Figure 6. C(11).jpg large image and partial zoom display.

2. Step 2: resize the image.

To facilitate the algorithm traversal to read the image and reduce the color extraction time, conduct equal proportional scaling of the image size, for example, 128 px. Set the image custom size parameters WIDTH, HEIGHT, that is, HEIGHT * (WIDTH/128) px.

3. Step 3: train the K-means algorithm to fit the model and predict clustering.

Receive the resized image and convert its parameters into a numpy array. Reshape the obtained array into a three-dimensional vector by the reshape method to represent the RGB values obtained. Then, create the color clusters in the image and the clusters using the KMeans() function, setting the hyperparameter n_clusters to the custom parameter CLUSTERS in Step 1, which is specified to be implemented by the Python library. Set the random seed random_state equal to zero.

Next, fit the image file to the model and perform clustering prediction to obtain the RGB values of the cluster centers, which are the primary colors of C(11).jpg. Then, create a dictionary named "cluster_map" using a DataFrame to store data such as the RGB values of pixels, hexadecimal codes, and the matched color names.

4. Step 4: match the cluster center (RGB value) from the dictionary to the query's actual/closest color.

Introduce the RGB values of the cluster center colors obtained through the K-means algorithm in Step 3 into the third-party module "webcolors" for conversion into color names. If the current color is displayed in the CSS3 color list, return the corresponding color name as the parameter actual_name. If not found, raise a ValueError.

Use a custom function called closest_color to find the closest color from the introduced color dictionary color_dict. This function calculates the Euclidean distance between the set of RGB values and all RGB values in color_dict, returning the closest color name.

5. Step 5: calculate the color percentage and draw a pie chart.

Using the clustering data dictionary obtained in Step 3, group by color hexadecimal codes and color names to obtain a "color_cluster" and find the total number of pixels (data points) within a specific cluster. Use the hexadecimal code and color name as the unique identification names for color matching in subsequent steps.

After the color extraction of the experimental sample is completed, import the other samples from the dataset into the color extraction algorithm. Finally, obtain the results of the Zhuang brocade color scheme extraction through algorithmic computation and control of the number of primary colors. As shown in Figure 7, the Zhuang brocade color scheme extraction results contain dataset sample number, sample display, sample primary color percentage, base color analysis, pattern color analysis, hexadecimal color code, and RGB code.

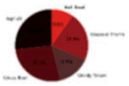
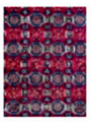
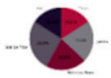
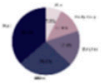
ID	Original image	Color proportions	Background color	Hexadecimal color code (RGB code)	Pattern color scheme	Hexadecimal color code (RGB code)
C1				#140a0c (20 10 12)		#b1382d (177 56 45) #7e6e75 (117 37 38) #4b3232 (75 50 50) #441517 (68 21 23)
C2				#5c0f30 (92 15 48)		#7b7b81 (23 23 29) #58515f (88 81 95) #8a1b3c (138 27 60) #1c142f (28 20 47)
C3				#13113e (19 17 62)		#dfd9dd (223 217 221) #aa93a1 (170 147 161) #6a637d (106 99 125) #393c5f (57 60 95)

Figure 7. Examples of extraction results for the color scheme of Zhuang brocade.

The extraction of characteristic colors of Zhuang brocade provides color materials for the design of Zhuang brocade patterns, facilitating subsequent research on the design and application of Zhuang brocade patterns. By employing the typical color combinations of Zhuang brocade, the aesthetic appeal of products can be enhanced, allowing more elements of Zhuang brocade to enter the public eye. This deepens users' understanding of Zhuang brocade and helps promote Zhuang brocade culture from a visual perspective.

3.3. Pattern Extraction Process and Results

As shown in Figure 8, to avoid issues such as sample image blur and complex texture interference during the pattern extraction process, which can affect the extraction results, the Relative Total Variation (RTV) model for texture smoothing and the Grabcut interactive image segmentation method are employed to fully extract the target patterns from the images. Then, binarization is applied to process the segmented image and realize the separation of the target image from the background.

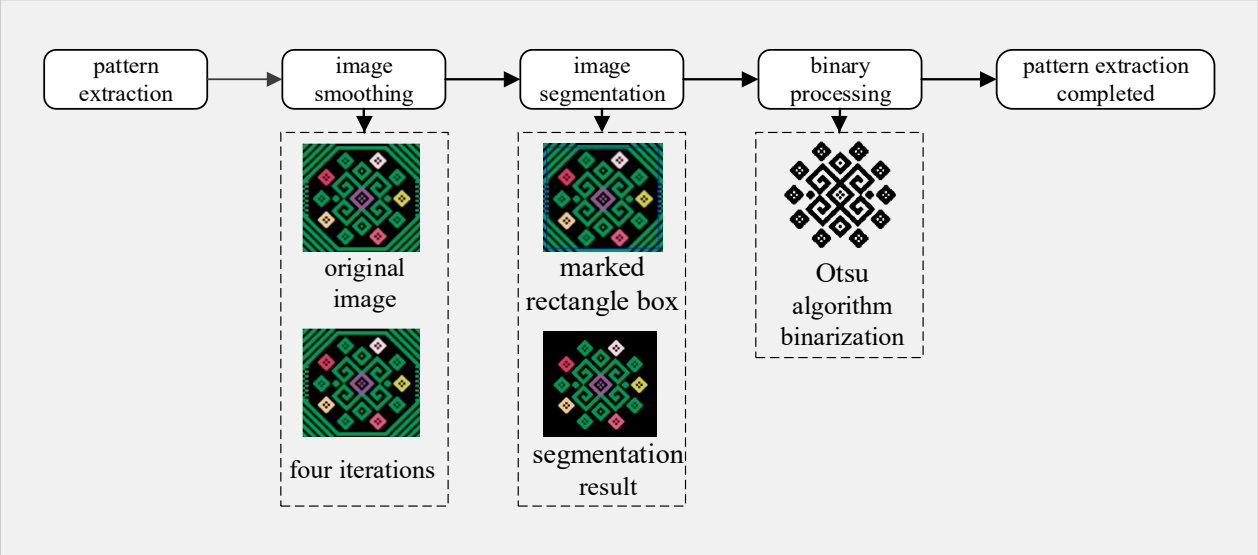


Figure 8. Flowchart showing color feature extraction of Zhuang brocade.

3.3.1. Image Smoothing

In order to reduce the interference of the textile's own tissue texture on the processing of pattern information, the Relative Total Variation (RTV) modeling algorithm is applied for the purpose of extracting texture smoothing. Texture smoothing aims to smooth the texture in the image while preserving salient structures [28]. The Relative Total Variation formula at any point p in the image is shown in (1):

$$\sum_{p}\left(\frac{\Phi_x(p)}{\Psi_x(p)+\varepsilon}+\frac{\Phi_y(p)}{\Psi_y(p)+\varepsilon}\right) \tag{1}$$

where ε is a fixed constant to prevent division by zero errors, $\varepsilon > 0$. The window full and intrinsic variants in the x and y directions for any point p in the image are:

$$D_x(f_p)=\sum_{q\in R(p)} h_{p,q}\cdot\left|\left(\partial_x f\right)_q\right| \tag{2}$$

$$D_y(f_p)=\sum_{q\in R(p)} h_{p,q}\cdot\left|\left(\partial_y f\right)_q\right| \tag{3}$$

$$L_x(f_p) = \left| \sum_{q \in R(p)} h_{p,q} \cdot (\partial_x f)_q \right| \tag{4}$$

$$L_y(f_p) = \left| \sum_{q \in R(p)} h_{p,q} \cdot (\partial_y f)_q \right| \tag{5}$$

where $R(p)$ is a rectangular region centered at p, q is any point in the variational region $R(p)$, x and y are the partial differentials of the pixel point q in the x and y directions, respectively, and $h_{p,q}$ are the weight functions defined according to the spatial,

$$h_{p,q} \propto \frac{exp\left(-\left((x_p - x_q)^2 + (y_p - y_q)^2\right)\right)}{2\sigma^2} \tag{6}$$

where x_p and y_p denote the horizontal and vertical coordinates of point p, respectively, and σ controls the window spatial scale in Formula (6).

The RTV algorithm is modeled as:

$$arg\ \min_f \sum_p \left[\left(f_p - S_p\right)^2 + \lambda \cdot RTV\left(f_p\right)\right] \tag{7}$$

where S denotes the input Zhuang brocade pattern, f denotes the image after the extracted structure, and λ is a fixed regularization parameter, representing the smoothing degree coefficient in Formula (7).

From the above model, it is evident that the degree of smoothing of the image by the RTV algorithm mainly depends on two parameters including the smoothing degree coefficient λ, and the spatial scaling parameter σ.

The smoothing degree coefficient generally takes a value between 0.005 and 0.03. Adjusting λ alone may not effectively separate texture and noise; only increasing λ may cause image blurring and keep the unwanted texture. Therefore, λ needs to be adjusted simultaneously with the spatial scale parameter σ. σ generally ranges from 0 to 6 and mainly regulates the spatial scale of the window, which depends on the size of noise or blotches in the image. Increasing σ can effectively remove noise interference and image blotches [21].

We take A03—Wansheng pattern from the pattern extraction dataset shown in Figure 3 as an example and adjust λ and σ within the above value ranges to smooth the Zhuang brocade pattern. The results show that the algorithm exhibits different levels of smoothness after various numbers of iterations, with convergence typically reached within four iterations.

The influence of the values of σ and λ on the image segmentation effect is demonstrated in Figure 9. In Figure 9a–d, for the plant pattern with less obvious texture, the smoothing effect is more obvious when σ increases to 2–3. However, some details of the pattern will be lost when $\sigma = 3$. Therefore, σ is selected as 2 for the printed fabric smoothing. Meanwhile, in Figure 9e–h, it can be seen that as λ increases, the details of the fabric pattern become smoother. Consequently, the coefficient for controlling the degree of smoothing λ is selected to be 0.01 to ensure a significant increase in the smoothing effect.

3.3.2. Image Segmentation Processing

GrabCut is an interactive image segmentation algorithm based on graph cut [29]. It requires the user to manually label the region to be segmented with a rectangle. The pixels inside the rectangle are considered as possible background and foreground, while the area outside the rectangle is defined as the background. Because of poor connectivity between patterns and tissues in Zhuang brocade patterns, the GrabCut algorithm is used for selective local segmentation.

The GrabCut algorithm implementation is as follows:

Take the A03—Wansheng pattern in the pattern extraction dataset shown in Figure 3 as an example. Open the terminal at the bottom of Pycharm and enter the command.

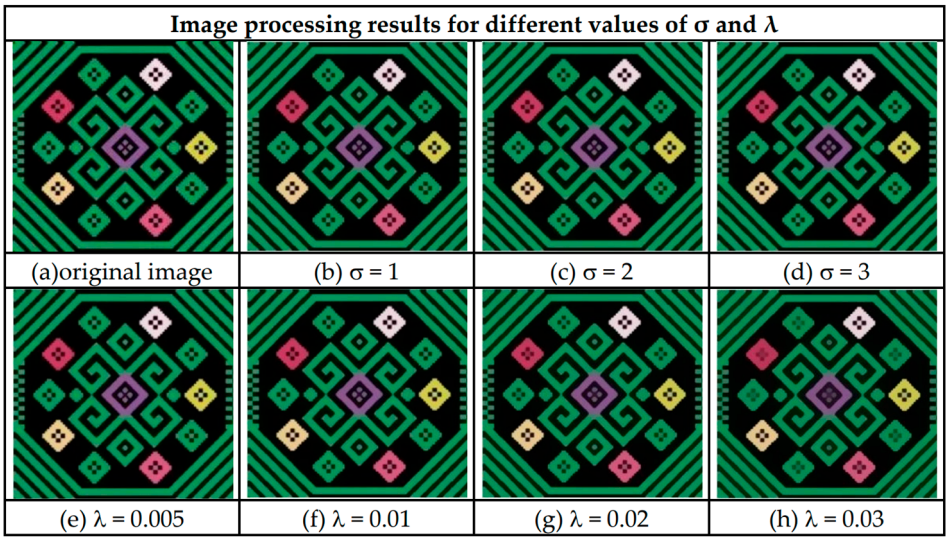


Figure 9. Image processing results for different values of σ and λ.

Two windows are displayed, one for the input window, displaying the initial image, and one for the output window, displaying the image after segmentation. In the input window, use the right mouse button to draw a rectangle in the target image area and then press "n" on the keyboard to confirm the segmentation of the object. The output window displays the segmented image in the rectangular box.

The sample segmentation process and results of this experiment are shown in Figure 10.

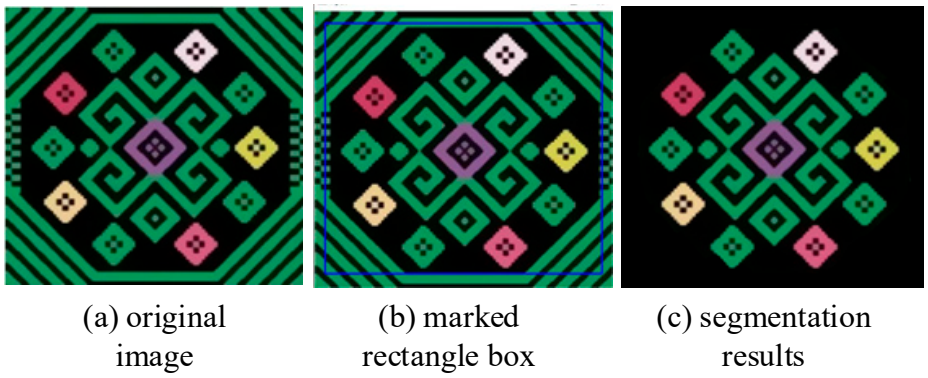


Figure 10. The sample segmentation process and results of the experiment.

3.3.3. Image Binarization

Image binarization is a basic technique of image processing, which can retain enough feature information [30]. The algorithm is mainly based on the gray level characteristics of the image, which is divided into two parts, i.e., the background and foreground, to achieve more refined image processing. The core idea is to find the maximized gray level k, i.e., Otsu's threshold, and then divide the image into two colors, black and white, which are larger than the threshold and smaller than the threshold. The specific algorithm principle is as follows:

For grayscale image F, consider it as an M × N matrix, i.e., pixels in the image with pixel values (0, 255). Let n_i be the number of pixels with gray level i, and p_i be the probability that a pixel is grayed out with i. Then,

$$p_i = \frac{n_i}{n_0 + n_1 + \cdots + n_{255}} \tag{8}$$

$$\sum_{i=0}^{255} p_i = 1 \tag{9}$$

The segmentation thresholds for foreground and background are denoted as k. According to the thresholds, the image is classified into two classes C_A (less than k) and C_B (greater than k). The probabilities of pixels being divided into C_A and C_B categories are p_A and p_B, respectively. The gray mean values of the two classes are denoted as m_A and m_B, respectively. The cumulative mean of the gray level K is m, and the global mean of the image is m_G.

Therefore, we have:

$$p_A(k) \times m_A(k) + p_B(k) \times m_B(k) = m_G \tag{10}$$

$$p_A(k) + p_B(k) = 1 \tag{11}$$

According to the concept of variance, the expression for variance is given by:

$$\sigma^2 = p_A(k)(m_A(k) - m_G)^2 + p_B(k)(m_B(k) - m_G)^2 \tag{12}$$

Bringing Equation (10) into Equation (12) yields:

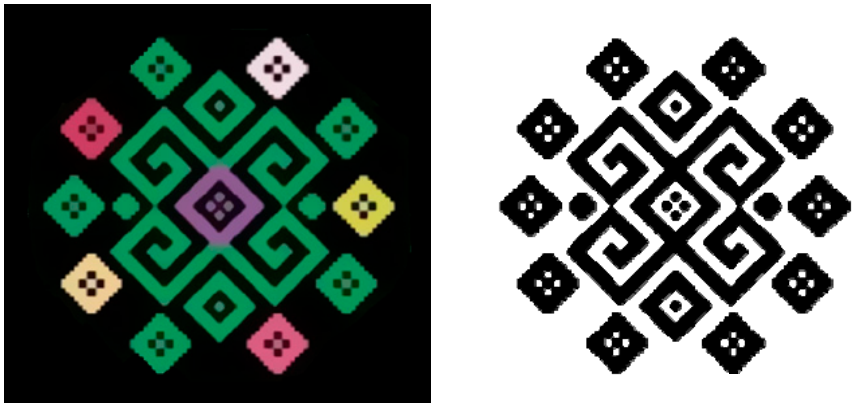
$$\sigma^2 = p_A(k)p_B(k)(m_A(k) - m_B(k))^2 \tag{13}$$

By iterating through possible threshold values, the threshold "k" that maximizes the inter-class variance can be determined.

Once the maximum threshold is obtained, image segmentation is performed through binarization:

$$img(i,j) = \begin{cases} maxval & if\ img(i,j) > threshold \\ 0 & otherwise \end{cases} \tag{14}$$

As shown in Figure 11, the Otsu algorithm is applied to obtain a binarized image, separating the target image from the background color. The final binarization result is presented in black and white, preserving the foreground target image to the greatest extent.



(a) original figure

(b) Otsu algorithm binarization

Figure 11. The binarized image obtained through the Otsu algorithm.

3.3.4. Pattern Extraction Results

Through image smoothing, segmentation, and binarization processes, pattern samples are obtained. Other samples from the dataset are then individually input into the algorithm. After undergoing each step to extract the basic morphology of the patterns, the feature extraction results for Zhuang brocade patterns are presented, as shown in Figure 12. This figure includes information such as sample ID, sample display, image after smooth-

ing, segmented image, and binarized result, providing fundamental elements for further pattern design.

ID	Sample	Smoothing	Segmentation	Binarization
A03				
B01				
C05				
D02				

Figure 12. Example results of pattern feature extraction.

Figure 12 presents example results of the pattern feature extraction. The experimental findings demonstrate that the algorithm introduced in this article exhibits outstanding robustness and is unaffected by the texture of the images. It rapidly segments target patterns and accurately predicts target pixels, minimizing prediction errors to a great extent. Additionally, it is user-friendly, requiring simple interactive operations for the target segmentation task.

During the extraction process of pattern textures, the smoothing parameters are adjusted based on the features of the original image. This adjustment aims to preserve the authentic texture of Zhuang brocade weaving. In the subsequent creative process, this approach enables the generation of results that closely resemble the texture perceived in actual woven fabric.

3.4. Organizational Form Extraction Process and Results

The organizational pattern of Zhuang brocade, typically diamond-shaped, is key to its unique style. In the process of extracting the organizational form of Zhuang brocade, as shown in Figure 13, a method is employed that references rules summarized in shape grammars and transformations of minimal units to achieve the desired pattern. In extracting Zhuang brocade patterns, observing minimal units and applying transformation rules efficiently draw the pattern's organization, ensuring its accuracy.

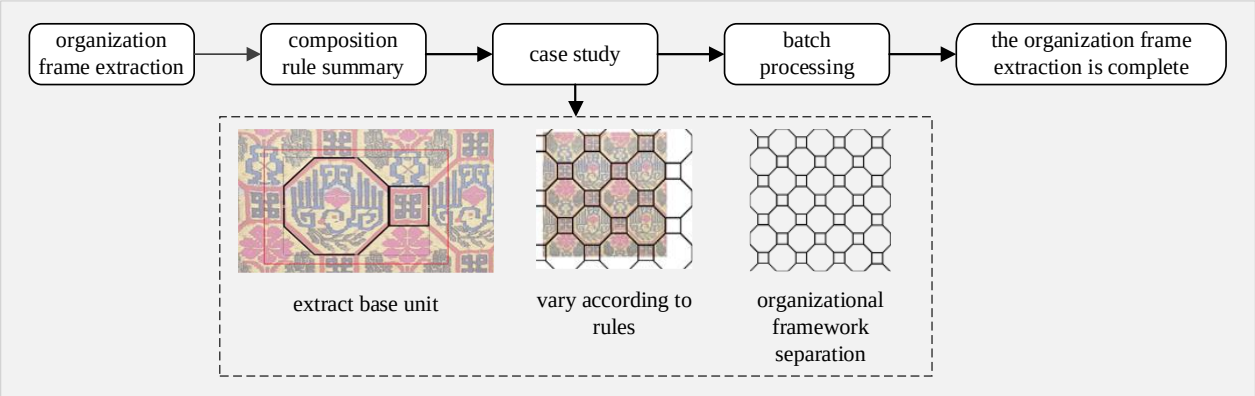


Figure 13. The process of organizational feature extraction from Zhuang brocade patterns.

The process of extracting organizational patterns from Zhuang brocade is undertaken by selecting common geometric patterns and the "卍" character pattern. As shown in Figure 14, two real samples are taken as cases for extracting organizational forms. All the extracted samples are processed to achieve a pattern with a 1:1 ratio.

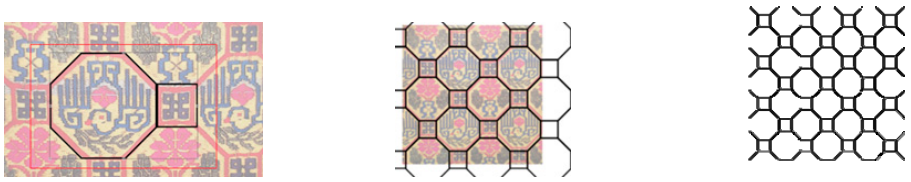


(a) case one (b) case two

Figure 14. The case of organizational form extraction from Zhuang brocade patterns.

(1) Process of organizational form extraction for Case One.

As shown in Figure 15, Case One's basic units consist of geometric shapes like octagons and squares, drawn with polygonal tools and completed by following specific rules.



1. Use the polygon tool to draw basic shapes. 2. Apply the matching rule of translation (R1). 3. Standardize the organizational form to 600*600px.

Figure 15. Process of extracting organizational forms in Case One.

(2) Process of organizational form extraction for Case Two.

The organizational extraction process for Case Two is similar to Case One. The basic unit for Case Two is formed by the "卍" character pattern, as shown in Figure 16. Considering the original image's color and clarity, adjustments are made to enhance image clarity. The smallest unit in this case is the "卍" character pattern, obtained by rotating a minimal unit in the shape of "7" according to Rule R2. This minimal unit is then utilized to derive the overall smallest basic unit. The transformation rules for the organizational pattern in Case Two involve translations (R1) and horizontal flips (R3) of the minimal unit "卍". To improve the matching accuracy between the extracted organizational form and the original pattern, the organizational form is standardized to a size of 600 * 600 pixels. This standardization facilitates subsequent pattern design applications.



Figure 16. Process of extracting organizational forms in Case Two.

Following the process described, the organizational patterns for Case One and Case Two are successfully extracted, matching the originals and validating the effectiveness and accuracy of the method. This approach is also applied to other samples, presenting complete patterns through translation, rotation, flipping, and other transformation rules. The results of Zhuang brocade organizational pattern extraction are shown in Figure 17. This figure includes sample ID, sample display, sample basic unit, transformation rules applicable to the sample, and the extraction result. The organizational form results are standardized to 600 * 600 pixels, contributing to increased accuracy in subsequent pattern design.

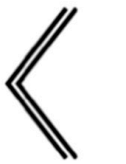
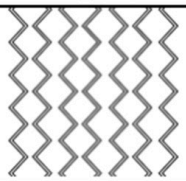
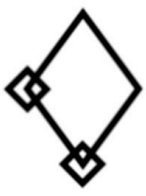
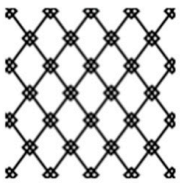
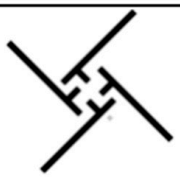
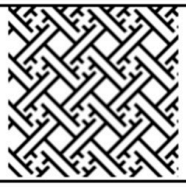
ID	Sample Display	Basic Unit	Transformation Rule	Extraction Result
01 diamond 1			R1 R3（R4）	
06 diamond + square2			R1	
10 Swastika pattern 1			R1+R3	

Figure 17. Example of pattern structure extraction results.

Integrating shape grammar rule induction reduces the impact of photography angles and fabric wrinkles on pattern extraction. By applying transformation rules such as translation, rotation, and flipping to the basic units of Zhuang brocade patterns, the unique organizational patterns of Zhuang brocade can be rapidly and effectively extracted.

4. Analysis of the Zhuang Brocade Pattern Generation Algorithm Based on Pattern Feature Elements

In order to rapidly generate Zhuang brocade patterns, this section conducts an analysis of the Zhuang brocade pattern design algorithm based on pattern feature elements. This study unfolds the composition of Zhuang brocade patterns, encodes feature materials, and proposes an algorithm for the automatic generation of Zhuang brocade patterns based on relative coordinates and region content replacement. This algorithm replaces the pattern with the target content of organizational forms based on relative coordinates. It matches the color schemes of a Zhuang brocade, generates multiple Zhuang brocade patterns, and evaluates their stylistic similarity. The main research process is illustrated in Figure 18.

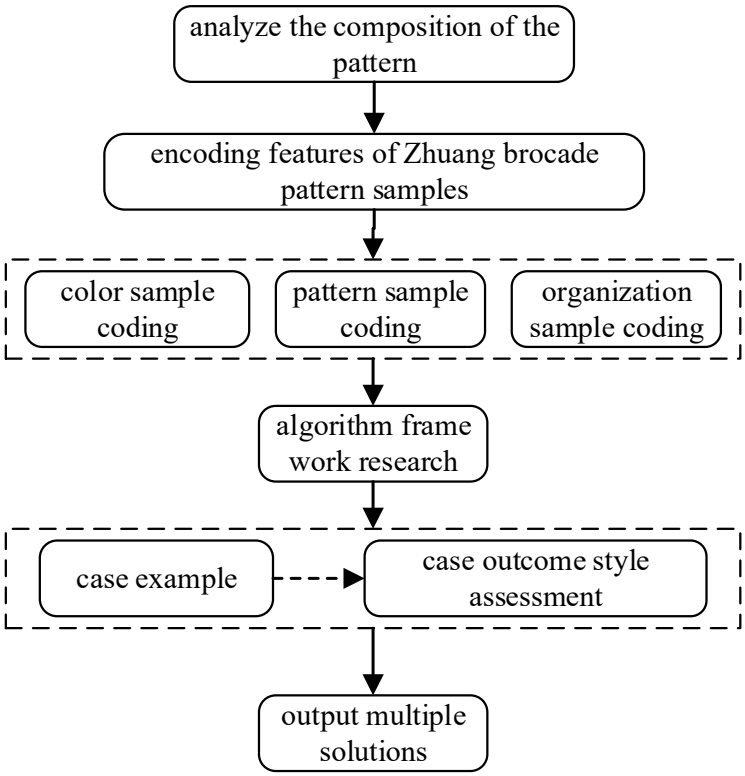


Figure 18. Research process of Zhuang brocade pattern design.

4.1. Pattern Sample Encoding

Binary encoding is applied to the feature elements of Zhuang brocade patterns, including color, design, and organizational form. The quantities of color, design, and organizational elements from Section 3 are converted into corresponding binary numbers. Binary, a widely used numeral system in computing, represents different element quantities with a fixed number of 0 s and 1 s, offering stability, regularity, and scalability, which facilitates adjustments for future additions of new elements.

4.1.1. Color Encoding

The weaving process of Zhuang brocade involves threading the warp and breaking the weft. In this process, the warp threads provide the background color, while the weft threads form geometric patterns with colored blocks. Color encoding is divided into two

parts as follows: the background color and pattern content color schemes, which include organizational form colors and pattern colors. Once the colors are determined, encoding is carried out for computer recognition and retrieval.

We extract background and content colors from 18 color samples to form 18 unique and fixed color schemes. Color encoding is divided into overall group encoding and individual encoding within each group, with each scheme uniquely coded, totaling 18 color schemes. Each color scheme is individually encoded for a total of 18 color schemes. Considering $2^4 < 18 < 2^5$, a five-bit binary number is needed for representation, ranging from 00000 to 10001, representing 18 color schemes.

Within each color scheme, individual colors present in that scheme are separately encoded. Since the maximum extracted pattern colorings from the samples are only five, for standardization, a three-bit binary number is used for encoding. As shown in Figure 19, 000 is fixed for the background color of Zhuang brocade patterns, and the other colors are encoded starting from 001. This generates the color encoding scheme. During the subsequent reconstruction of Zhuang brocade patterns, coloring is performed on a group basis according to the color scheme. The reconstructed patterns can utilize different background colors and other single colors from within the color group for coloring, creating multiple color schemes for Zhuang brocade. This provides various design options for easy selection and application in the future.

Color scheme	Color group/Single color code		Color scheme	Color group/Single color code		Color scheme	Color group/Single color code		Color scheme	Color group/Single color code	
	00000	000 001 010 011 100		00101	000 001 010		01010	000 001 010 011 100		01111	000 001 010 011 100
	00001	000 001 010 011 100		00110	000 001 010 011		01011	000 001 010 011 100		10000	000 001 010 011 100
	00010	000 001 010 011 100		00111	000 001 010 011		01100	000 001 010 011 100		10001	000 001 010 011 100
	00011	000 001 010 011 100		01000	000 001 010 011 100 101		01101	000 001 010 011 100			
	00100	000 001 010 011 100		01001	000 001 010 011		01110	000 001			

Figure 19. Color groups, individual colors, and their codes.

4.1.2. Pattern Encoding

As shown in Figure 20, a total of 27 classical patterns were extracted in the previous section. Since $2^4 < 27 < 2^5$, using a five-bit binary number for encoding is most suitable. The encoding from 00000 to 11010 represents the 27 classical patterns, making it convenient for computer recognition and retrieval.

Pattern	Code	Pattern	Code	Pattern	Code	Pattern	Code	Pattern	Code
	00000		00110		01100		10010		11000
	00001		00111		01101		10011		11001
	00010		01000		01110		10100		11010
	00011		01001		01111		10101		
	00100		01010		10000		10110		
	00101		01011		10001		10111		

Figure 20. Basic patterns of Zhuang brocade and their codes.

4.1.3. Organizational Form Encoding

Zhuang brocade typically features a diamond interlacing as the fundamental structure, with continuous square geometric patterns, where two kinds of patterns are alternately arranged, each taking up half of the space.

As shown in Figure 21, building on the successful extraction of 15 Zhuang brocade organizational patterns in Section 3.4, a four-bit binary number is used for encoding because $2^3 < 15 < 2^4$. The numbers 0000 to 1110 respectively represent these 15 organizational pattern forms.

4.2. Zhuang Brocade Pattern Design Research

In the research of Zhuang brocade pattern design, this study is conducted using the common Swastika pattern as a base, adorned with animals, plants, and auspicious character patterns. As shown in Figure 22, by individually encoding each element of Zhuang brocade, the genetic unit of each Zhuang brocade consists of the following four parts: color group, organizational form, pattern 1, and pattern 2. Each pattern is composed of different styles and color schemes. Combining the encoding of different elements in Zhuang brocade, the genotype is represented by a 19-bit binary number. The first five digits represent 18 different color schemes, namely, the color group. The next four digits represent 15 pattern organizational forms, and the last ten digits represent two different pattern styles selected from the 27 pattern samples.

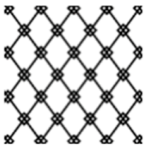
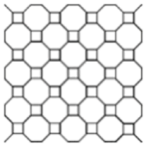
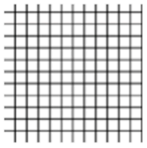
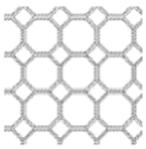
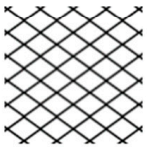
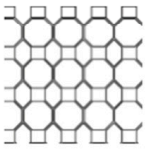
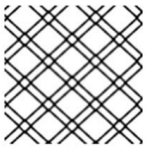
Organizational Forms	Code	Organizational Forms	Code	Organizational Forms	Code
	0000		0101		1010
	0001		0110		1011
	0010		0111		1100
	0011		1000		1101
	0100		1001		1110

Figure 21. Zhuang brocade pattern organization forms and their codes.

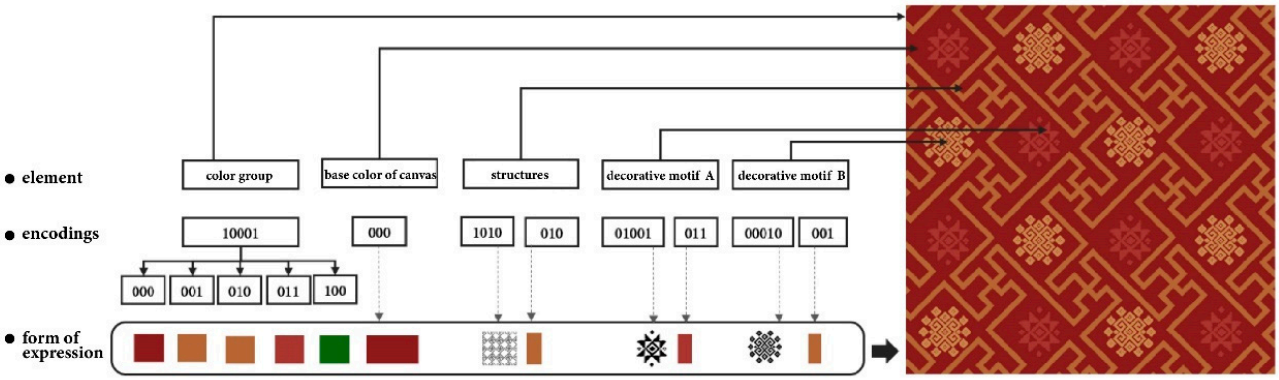


Figure 22. Zhuang brocade genotype coding and representation.

To facilitate the automated generation of different element-reconstructed patterns, the organizational form images of Zhuang brocade patterns are uniformly defined as squares with dimensions of 600 * 600 pixels. The genotype binary numbers are separated by spaces to distinguish among different pattern elements. For example, 10001 1010 00010 01001 represents a new Zhuang brocade pattern reconstructed from color scheme C18, organizational form No. 11, and two pattern patterns with the IDs A03 and A10.

4.2.1. Algorithm Design and Framework

As shown in Figure 23, the Zhuang brocade reconstruction algorithm uses the binary encoding of elements to create a mapping file, decodes the genetic pattern code to retrieve the corresponding elements, aligns the center coordinates of the organizational form patterns with those of the patterns to be recombined, constructs new patterns using a specified image replacement method, and applies the color scheme to achieve the final result.

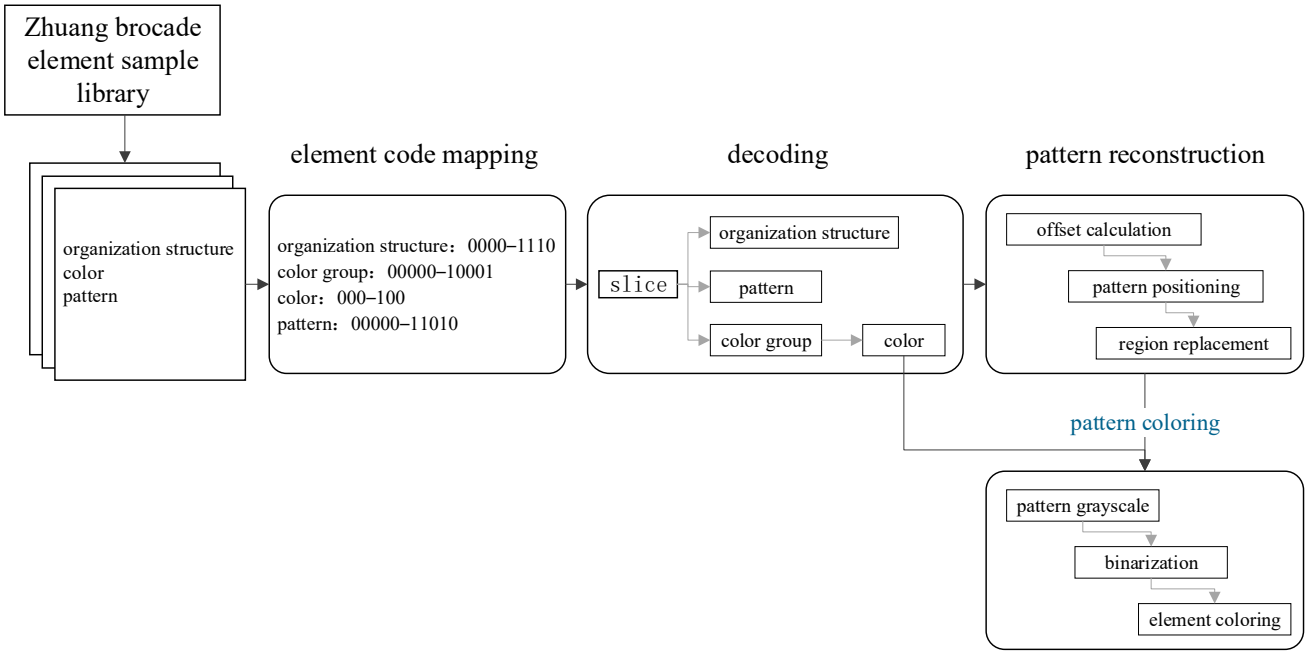


Figure 23. Algorithm framework.

(1) Step 1: generating the element encoding mapping file.

Based on the binary encoding obtained for all Zhuang brocade elements in Section 4.1, a JSON file named code_map.json is created in the project. The JSON file is divided into three levels: pattern path mapping (pattern_path), structure path mapping (structure_path), and color group (color_group). It maps folder elements, image files, and JSON files at each level.

(2) Step 2: decoding.

Each reconstructed Zhuang brocade pattern is composed of a 19-bit binary code in the following format: color scheme, organizational form, pattern A, and pattern B, with spaces as separators. The mapping file code_map.json from the first step is introduced and the json.load() method is used to convert the imported JSON object into a Python dictionary, named img_dict. This dictionary makes it easy to look up mapping elements based on the code later.

The decoding function is decode(code), which takes a 19-bit binary pattern gene code as a parameter. Using the string.split() method with a default space separator, the 19-bit binary code is sliced, and the function returns a list of strings [color_group_code, structure_code, patternA_code, patternB_code], representing the color group code, organizational form code, pattern A code, and pattern B code.

By indexing each element code, the function looks up the corresponding paths in the img_dict. For example, img_dict['structure_path'][structure_code] retrieves the image path for the organizational form. Similarly, for pattern A and pattern B, the color group code is used to retrieve a dictionary composed of RGB values and codes for each color in the color group.

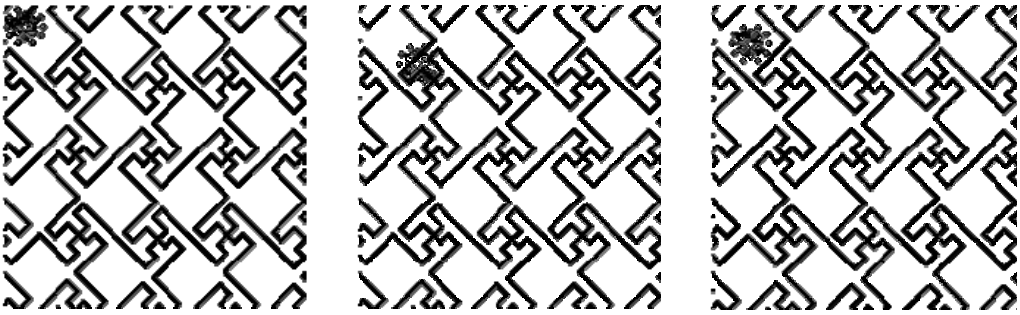
(3) Step 3: Zhuang brocade pattern reconstruction.

Pattern reconstruction mainly involves reassembling the extracted pattern images and organizational forms from Section 3. By combining them in various ways, a range of new Zhuang brocade patterns can be created. The central point of the pattern image is aligned with that of the organizational form, achieving a recombination of the two. The image.paste function from the Python Image Library is utilized to replace the specified region's image, completing the pattern reconstruction. The decoded image is in PNG format and needs to be converted to the RGBA image format recognizable by the computer.

In the image.paste method, the organizational form is used as the background image. The origin is set at the top-left corner of the image, with the x and y axes extending to the right and down, respectively. The parameter box is optional, using a tuple as an example. When the box is a tuple, it represents the coordinates of the top-left corner of the pattern image in the coordinate system. In Figure 24a, when box is set to None or box = (0, 0), it means the top-left corner of the pattern image is aligned with the top-left corner of the background image, placing the pattern image pasted onto the top-left corner of the organizational form. In Figure 24b, assume the center coordinates of the organizational form pattern area and the pasted area S_0 are (x_0, y_0). When box = (x_0, y_0), the top-left corner of the pattern image is located at the center point of S_0, overlapping the pattern with the organizational form. In Figure 24c, the pattern image is offset to the top-left, with x and y axes offsets equal to half of the pattern image's width and height in pixels. At this point, the pattern image overlays the area S_0. Thus:

$$x = x_0 - patternA.width/2 \tag{15}$$

$$y = y_0 - patternA.\,height/2 \tag{16}$$



(a) paste pattern motif (b) offset pattern motif (c) position pattern motif

Figure 24. Demonstration of pattern position matching process.

In the above equations, the tuple (x, y) forms the parameter box, where pattern A represents pattern A, and width and height denote two image attributes of pattern A, specifically, its width and height, both measured in pixels (px).

All pattern regions S_n in the organizational structure are iterated through and the decoded pattern images are pasted into their corresponding positions according to different arrangement rules.

(4) Step 4: recoloring the reconstructed pattern.

The pattern images and organizational structures extracted in Sections 3.3 and 3.4 are both black-patterned images with a white background in PNG format. The core idea of recoloring is to perform binary thresholding on the images. Then, a masking approach is used to colorize the parts outside the preserved color regions. The mask is used to cover selected areas, namely, the pattern images and the organizational structures, controlling the regions of image processing.

A function named color.py is defined, which takes the following two parameters: img representing the image to be colored and colorGroup representing the color group. The image img is obtained by invoking the reconstruction method from the third step, and the color group is obtained through the decoding process from the first step. The function implementation involves the following steps:

A. Use the cv2.imread(img) method to read the image. At this point, the image format is BGR.
B. Convert the image to grayscale using the color space conversion function cv2.cvtColor (img, cv2.COLOR_BGR2GRAY). Here, img is the result returned by step A, and cv2.COLOR_BGR2GRAY indicates the conversion from BGR format to grayscale.
C. Use the grayscale image obtained from step B as the src parameter in the cv2.threshold (src, thresh, maxval, type[, dst]) function. This function performs binary thresholding on the grayscale image, returning retVal and dst for subsequent image processing. In this context, src represents the image source (i.e., the grayscale image), thresh denotes the threshold (initial value), and maxval indicates the threshold (maximum value), set to 0 and 255, respectively. The type parameter selects the method, employing a combination of cv2.THRESH_BINARY_INV and cv2.THRESH_OTSU. cv2.THRESH_OTSU utilizes the least squares method to process pixel points, seeking the optimal threshold, while cv2.THRESH_BINARY_INV sets the binarization color—pixels greater than the threshold are set to 0 (black), and those less than the threshold are set to maxval, i.e., 255 (white). The returned value retVal is the threshold value, and dst represents the resulting black-and-white image.
D. The color group colorGroup obtained in step A is in list format, containing all color codes and corresponding RGB values in the color group. RGB values are assigned corresponding to the colors to the parts outside the mask, i.e., img[mask] = RGB. The mask specifies the areas to be preserved from replacement, taking values of 0 or 255, and RGB represents the color to be substituted.

Coloration is applied separately to the reconstructed Zhuang brocade patterns in the organizational form, pattern A, pattern B, and the background. The color distribution is determined by randomly combining single colors from within the color group, ensuring distinctiveness and avoiding repetitions. The final colored Zhuang brocade patterns are saved as PNG format images using the cv2.imwrite() method.

4.2.2. Case Examples

Among the extracted element samples, we randomly select a color group, organizational structure, and two different patterns. Here, we take the example of the C18 color group, S11 organizational structure, A10 pattern, and A03 pattern, corresponding to the 19-bit binary code "10001 1010 01001 00010".

(1) Step 1: decoding.

Call the decode(code) function, passing the parameter code = "10001 1010 01001 00010". Split the code by spaces and look up the values corresponding to the code in the imported mapping file code_map.json. Return the color group (color_group), organizational structure (structure), pattern A (pattern A), and pattern B (pattern B).

(2) Step 2: pattern reconstruction.

Define a parameter list with a data type of a list to receive the data returned from the first step of decoding. Read the organizational structure and pattern images and convert them to RGBA channels. Calculate the offset distance for the two patterns, which should be half the size of the images. Paste patterns A and B into the blank spaces of the organizational structure sequentially, aligning their centers. Obtain the reconstructed image, as shown in Figure 25.

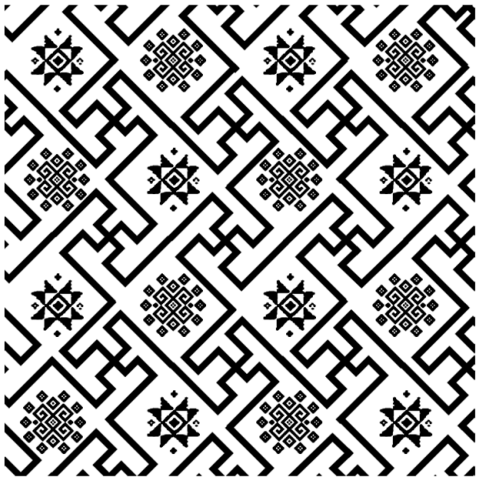


Figure 25. Example of a reconstructed image.

(3) Step 3: pattern recoloring.

Call the color(img, colorGroup) function, passing the reconstructed image and color group obtained in the first and second steps. The C18 color group has a total of five colors, with color codes ranging from 000 to 100. The color with the code 000 corresponds to the background color of the reconstructed pattern, while the other four colors are randomly selected. Three of them are assigned to the organizational structure and pattern images with different colors. As shown in Figure 26, the colors of the elements ensure diversity, resulting in a total of $A_4^3 = 4 * 3 * 2 * 1 = 24$ possible outcomes.

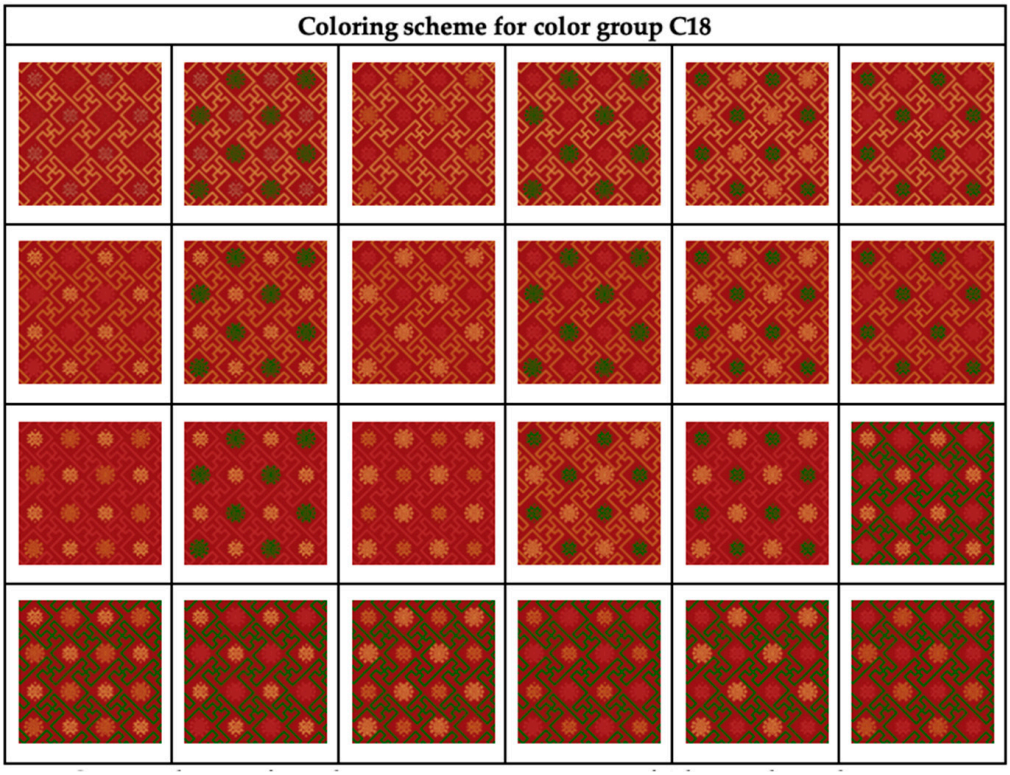


Figure 26. Coloring scheme for color group C18.

The case studies confirm that the automatic generation of Zhuang brocade patterns is feasible using characteristic elements, relative coordinates, and regional content replacement. By further applying the color, pattern, and organizational structure features of Zhuang brocade patterns, 10 Zhuang brocade patterns are rapidly generated. The results are shown in Figure 27, providing evidence that this algorithm and process can enhance the efficiency of innovation in Zhuang brocade patterns.

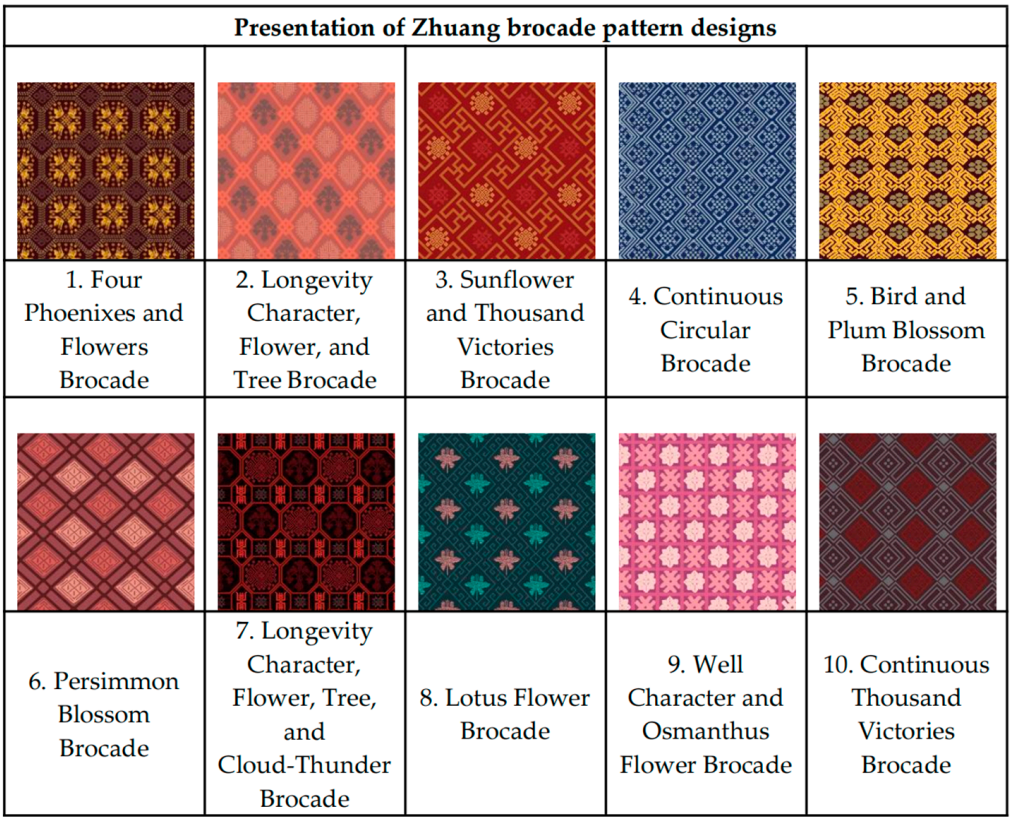


Figure 27. Presentation of Zhuang brocade pattern designs.

4.3. Zhuang Brocade Pattern Style Similarity Evaluation

To validate the effectiveness of the algorithm and process for designing Zhuang brocade patterns based on the features of Zhuang brocade elements, a user similarity evaluation was conducted to confirm the style similarity of Zhuang brocade patterns.

The evaluation involved inviting 30 users as testers to assess the style of 10 patterns in comparison to the Zhuang brocade patterns in the collection. The 30 participants included 12 Zhuang individuals, seven Zhuang brocade researchers, and 15 random users. The evaluation options included three choices as follows: similar style, dissimilar style, and neutral, as shown in Table 1. The percentage for each option was calculated and analyzed.

The data from the style similarity evaluation table indicates that 9 out of the 10 patterns were evaluated as similar, accounting for 90% of the evaluation samples. The calculated average style similarity evaluation for the 10 generated patterns is 75.67%, suggesting a consistent level of acceptance among testers, regardless of their familiarity with Zhuang brocade. By applying pattern genes and incorporating organizational patterns and Zhuang brocade color schemes, the algorithm successfully preserves the style and characteristics of Zhuang brocade, highlighting the feasibility of the design approach.

Table 1. Style similarity evaluation table for generated patterns.

Pattern Number	Similar	Dissimilar	Neutral
1	83.33%	10.00	6.67
2	76.67%	13.33	10.00
3	93.33%	0.00	6.67
4	76.67%	13.33	10.00
5	63.33%	10.00	26.67
6	76.67%	10.00	13.33
7	76.67%	6.67	16.67
8	90.00%	3.33	6.67
9	46.67%	23.33	30.00
10	73.33%	10.00	16.67

5. Conclusions

In response to the current lack of innovation in the inheritance of Zhuang brocade patterns, this article proposes a method for automatically generating Zhuang brocade patterns based on relative coordinates and region content replacement. Firstly, intelligent extraction algorithms and processes were designed to effectively capture color schemes, patterns, and organizational forms, forming a feature dataset. Secondly, the feature materials of Zhuang brocade patterns were encoded for computer recognition. Finally, by studying individual cases of Zhuang brocade pattern design, the algorithm based on Zhuang brocade genotype coding and region content replacement was employed to achieve the automatic generation and validated for effectiveness.

This article focuses on common color schemes, patterns, and organizational forms of Zhuang brocade. It accurately applies the common color combinations of Zhuang brocade to the canvas background, patterns, and organizational forms in the pattern design process. However, it does not address the coloring of different regions within individual patterns. In future research, further algorithmic improvements should be made to enhance the pattern diversity and generate more output options.

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