Architectural Pattern Extraction based on Image Enhancement Technology

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Abstract. Extracting traditional patterns is one of the essential steps in the digital protection and inheritance of cultural heritage. Aiming at the problem that there is no standard and efficient workflow for the extraction of decorative architectural patterns, this paper takes the Yuelu Academy of Classical Learning's architectural decorative patterns as an example and proposes a universal, systematic, and standardized extraction workflow for traditional patterns based on image enhancement technology and computer-aided design tools. This extraction workflow reduces the difficulty of identifying and extracting traditional architectural patterns due to changing times, natural environment replacement, and human factors and provides a standardized process for digitizing traditional patterns. It promotes the digital inheritance of conventional patterns and the construction of a design material library and offers new ideas for material cultural heritage digital protection.

Keywords: Traditional Patterns, Pattern Extraction, Image Enhancement, Computer-Aided Design, Yuelu Academy.
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1 INTRODUCTION

Chinese traditional architecture is the most splendid and intuitive inheritance carrier and expression form of China's long-standing conventional culture and national characteristics. As one of the explicit carriers of conventional culture, traditional architectural patterns also have the exemplary significance of cultural inheritance. At the level of cultural value, digital archiving of decorative architectural patterns to help spread traditional culture and expand the influence of excellent conventional culture is of great significance in activating the inherent strong vitality of Chinese fantastic traditional culture and strengthening cultural confidence. Yuelu Academy is one of the famous "Four Academies of Classical Learning" in ancient China and one of the world's oldest learning seats. Its ancient architectural complex has been completely preserved to this day and is a typical representative of traditional Chinese architecture and academy culture. Yuelu Academy includes functional buildings such as lecture halls and libraries, commemorative architecture such as the Confucian temple, and landscape buildings such as pavilions. Therefore, the decorative patterns of the academy buildings reflect the Chinese academy of classical learning culture, covering the ancient life culture and traditional customs. They can comprehensively display the conventional Chinese architectural patterns and are of exemplary significance.

Under changing times and environmental changes, decorative architectural patterns have appeared to be damaged to varying degrees and inevitably. Digital extraction of architectural patterns is one of the critical tasks for protecting traditional architectural heritage at present. With the development of computer-aided design technology, more and more researchers are promoting the innovation and application of computer image technology in pattern digitalization. In terms of image enhancement, Khadidja Kaibiche et al.[1] successfully restored stained old manuscripts by a system combining wavelets and bilateral filtering. Sonali et al.[2] combined a filter with the Contrast-limited Adaptive Histogram Equalization (CLAHE) algorithm to optimize the noise problem of medical fundus images. Weiying Piao et al.[3] proposed an image denoising algorithm based on Gaussian filtering and bilateral filtering, which effectively overcomes the staircase effect caused by single bilateral filtering. In terms of symbol and pattern extraction, Sun Muzi et al.[4] proposed a new pattern extraction algorithm based on grayscale, binary, and contour tracking methods for the contour extraction and vectorization of traditional Chinese paper-cut, which improved the pattern of the piecewise displacement curve segments vectorization method. Daoling Chen et al.[5] used the morphological method combined with the Canny algorithm to achieve a relatively complete extraction of patterns on batik fabrics. Dong Han et al.[6] took hyperspectral imaging technology as the core, combined image correction algorithm based on the Bicubic interpolation and Moving Least-Squares (MLS) and the high-pass filter to discover and extract the “Kuilong” pattern on No. 2 Qin Bronze Chariot.

These researches have promoted the application and innovation of computer-aided design technology in traditional pattern extraction, but they still have certain limitations. First, the patterns extracted by some of the above research are relatively simple, and the extracted patterns are not complete enough to support designers in redesigning them. Secondly, due to the diverse carriers, complex patterns, and different shapes of decorative architectural patterns, it isn't easy to completely rely on computer technology to extract them. Besides, architectural decoration is widely distributed in roofs, ridges, cornices, bucket arches, etc. It limits the material shooting of the architectural ornaments of Yuelu Academy, resulting in low image quality of some original materials, increasing the workload of image preprocessing, and the difficulty of pattern recognition and extraction. Therefore, extracting decorative architectural patterns cannot achieve ideal digital results only by relying on computer image technology. Combining image enhancement technology and computer-aided design tools is necessary to optimize the extraction process.

Aiming at the above problems, this paper takes the decorative patterns of Yuelu Academy buildings as the specific research object and proposes a universal and systematic workflow for extracting architectural patterns. It includes material collection, image enhancement, and pattern standardized correction, as shown in Figure 1.

2 COLLECTION AND ANALYSIS OF ARCHITECTURAL PATTERNS OF YUELU ACADEMY

Yuelu Academy is the best-preserved ancient academy of classical learning in China, and its buildings have essential historical, cultural, and artistic value. The ancient buildings of Yuelu Academy have gone through Song, Yuan, Ming, and Qing dynasties. Its architectural decoration reflects the aesthetic pursuit of literati and students of the past dynasties and reflects the humanistic spirit of the academy and the concept of ancient creations.

The architectural patterns of Yuelu Academy can be divided into plant patterns, animal patterns, geometric patterns, and combined patterns; terms of patterns. They can be divided into three categories: individual patterns, suitable patterns, and continuous patterns; in terms of materials, they can be divided into four types: wood, stone, brick, and glass. The pattern contains elements of auspiciousness, disaster prevention, and the literati spirit.

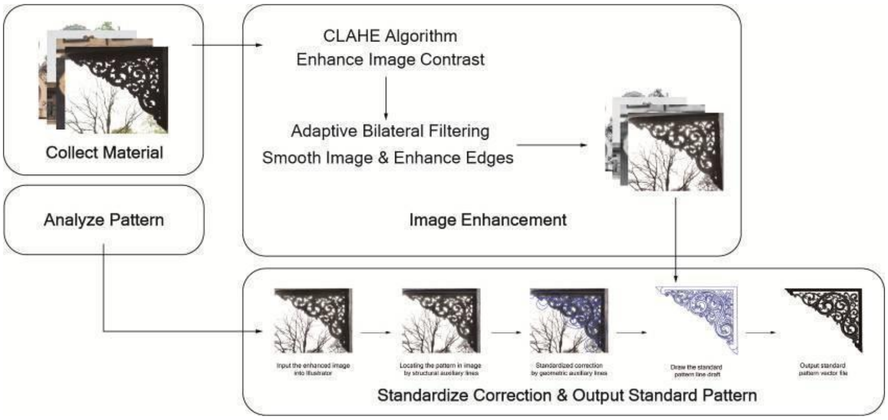


Figure 1: The extraction workflow of traditional architectural decorative patterns.

In terms of meaning, it can be divided into three themes: the theme of home-guarding and praying for blessings, which expresses the ancients' longing for longevity and peace, and the theme of Confucianism and education, which encourages students to cultivate themselves and self-discipline, as well as the theme of the literati character showing the moral literacy of ancient scholars. This paper collects many pictures of Yuelu Academy’s architectural decorations and organizes them in Figure 2. The typical architectural ornaments are analyzed and summarized using the chart analysis method, as shown in Table 1.

(a) (b) (c) (d) (e) (f) (g)

Figure 2: The typical architectural decorations of Yuelu Academy.

Pattern Type	*Figure Number*	*Pattern Name*	*Location*	*Pattern Form*	*Pattern Elements*
Plant Pattern	(a)	Vol-Grass Pattern	He Xi Platform’s Bracket of Beams and Columns	Corner Fit	Roll Grass
	(b)	Peach Pattern	Yuelu Academy Tablet’s Bracket	Shape Fit	Peach, Peach Blossom
	(c)	Peony Pattern	He Xi Platform’s Ridge	Two-sided Continuous	Peony, Roll Grass
Animal Pattern	(d)	Chi Wen	Ji Quan Pavilion’s Ridge	Single Equilibrium	Dragon
Geometric Pattern	(e)	Geometric Pattern	He Xi Platform’s Stone Fence	Symmetrical Individual	Circle, Curve
Combined Pattern	(f)	Kirin Pattern	Da Cheng Hall’s Ridge	Equilibrium Fit	Kirin, Bookcase, Roll Grass

(g)	San-yuan-ji-di Pattern	He Xi Platform's Eaves Brace	Shape Fit	Longas, Magpie, Stone

Table 1: The classification of pattern characteristics of typical samples.

As shown in Table 1, there are three primary forms of decorative architectural patterns in Yuelu Academy: individual patterns, appropriate patterns, and continuous patterns.

The individual pattern is a pattern that does not connect with its surroundings and can exist independently or be used alone. There are two types of it: symmetrical and balanced. The symmetrical type is based on the central axis or center point. The same shape and the same amount of patterns are arranged in all directions of the fixed central axis or center point; The uniform form is not limited by the axis and can be freely organized and arranged. Appropriate patterns are organized within the limits of the outline, which can be divided into three forms: suitable shape, suitable corners, and suitable edges. There are five main types of organization in the outer contour line: symmetrical, balanced, centrifugal, centripetal, and rotary. The continuous pattern refers to the constant patterns formed by a repeated arrangement of one pattern unit, generally divided into two forms: two-sided continuous and four-sided continuous. The two-sided continuous pattern refers to an infinitely continuous unit pattern in two directions, up and down or left and right. There are three main types: symmetrical, balanced, and hybrid. The analysis of pattern form features is shown in Table 2.

Figure Number	*Pattern Form*	*Pattern From Features*
(a)	Corner Fit	The two sides are vertical, the pattern is like a right triangle
(b)	Shape Fit	The outline is centrosymmetric, and the inner patterns are arranged according to the outline
(c)	Two-sided Continuous	Bilateral symmetry
(d)	Single Equilibrium	S-shaped pattern
(e)	Symmetrical Individual	Axial symmetric pattern
(f)	Equilibrium Fit	Symmetrical borders, with a separate pattern at the center of the pattern
(g)	Shape Fit	The outline is axisymmetric, and the inner patterns are arranged along the outline

Table 2: The analysis of the form features of typical samples.

3 EXTRACTION WORKFLOW OF DECORATIVE ARCHITECTURAL PATTERNS

The pattern extraction workflow mainly relies on python8, MATLAB, and illustrator for experiments and research, divided into image enhancement, standardized correction of patterns, and extraction. It is an interactive workflow relying on computer image technology and computer-aided design tool.

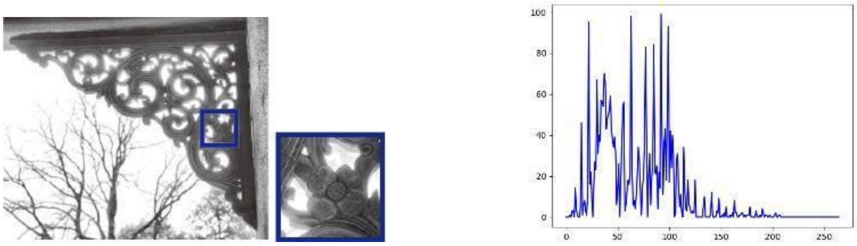
3.1 Image Enhancement

The images shown in Figure 2 are typical samples with image quality problems in the architectural decoration pattern materials. Fig.2(a) is the underexposed image, Fig.2(b)(c)(d)(f)(g) are the images with lower resolution, and Fig.2(g) is the pattern with the same color as the background. To optimize the image quality of the original material so that the material can have a better human eye recognition effect and assist pattern extraction. This section uses the Contrast-limited Adaptive Histogram Equalization (CLAHE) algorithm combined with Adaptive Bilateral Filtering (ABF) to perform batch image enhancement on the original material and assess the results.

3.1.1 Image Contrast Enhancement

Due to environment, light, and distance, the pattern images we take have different degrees of low definition, too bright or too dark. The CLAHE algorithm[7] clips the histogram with a pre-defined threshold before calculating the cumulative histogram function (CDF) around the pixel. It evenly distributes the clipped part to the rest of the histogram to increase the image contrast and limit the amplitude of noise amplification. The image contrast enhancement result of the CLAHE algorithm is shown in Figure 3 (d).

(a) Input image and regional close-up (b) Grayscale histogram of (a)



(c) Enhanced result and regional close-up (d) Grayscale histogram of (c)

Figure 3: Comparison of the original image and CLAHE algorithm enhanced results.

After enhancement, the gray value of the image is uniformly stretched by the local contrast limit, as shown in Figure 3(d). The dark areas of the image are significantly improved, offering more pattern details, as shown in Fig. 3(c).

3.1.2 Image Smoothing

According to the image enhancement results of the CLAHE algorithm, the contrast enhancement of the picture will also cause different degrees of noise enlargement, which increases the difficulty of identifying the details of some complex patterns.

To reduce the influence of excessive noise on the recognition of pattern details, an Adaptive Bilateral Filtering(ABF) algorithm[8][9] is used to smooth the noise of the enhanced images based on preserving the edge features of the patterns, which avoids the time cost and error caused by taking empirical values of spatial parameters and grayscale parameters. The algorithm uses the bilateral filter window size and the image noise variance to obtain the image space variance and grayscale variance. It adaptively obtains the optimal image smoothing parameters according to different photos. The smoothing result is shown in Figure 4(c).

Figure 4: Overall process and result of ABF.

Figure 4(a) is the input image, (b) is the image after CLAHE algorithm enhancement, (c) is the result of the ABF algorithm smoothed, and (d) are close-ups of regions.

According to Figure 4, it can be seen that bilateral filtering eliminates image noise based on retaining the edge of the pattern, simplifies some redundant details of the pattern, increases the recognizability of the pattern, and reduces the difficulty of subsequent pattern extraction.

3.1.3 Image Quality Assessment

For the assessment, the fuzzy comprehensive evaluation and the image structural similarity algorithm (SSIM) were used to compare and evaluate the image enhancement effect of the proposed algorithm and the image enhancement effect of Photoshop2021's automatic contrast command. the Auto Contrast command in Photoshop 2021. The adjustment by Photoshop is to import the picture into Photoshop2021 and execute the "Image - Auto Contrast" command. This command can automatically enhance the contrast of the brightness and darkness of the image, increase the layering of the image, and make the picture look clearer. Combined with the evaluation results of subjective pattern recognition and objective image structure similarity, the effectiveness and superiority of the method of combining the CLAHE algorithm and the Adaptive Bilateral Filtering for image enhancement are verified.

Before carrying out the fuzzy comprehensive evaluation, the relevant experts selected three evaluation indicators, and combined with the pattern extraction requirements; the three evaluation indicators were given corresponding weights. They are the recognition degree of pattern outline (W_{f1} = 0.35), the degree of distinction between the main pattern and the image background (W_{f2} = 0.15), and the recognition degree of pattern details (W_{f3} = 0.50), as shown in Table 3.

Evaluation indicators	*Description of evaluation indicators*	*Evaluation weight(W)*
f1	The recognition degree of pattern outline	0.35
f2	The degree of distinction between the main pattern and the image background	0.15
f3	The recognition degree of pattern details	0.50

Table 3: Image enhancement effect evaluation indicators and evaluation weights.

Among them, the index f3 is the main target of image enhancement, so the weight value assigned by experts is the highest, and the index f2 is the correlation index of f1, so the weight given by experts is the lowest. The evaluation level is divided into five levels: excellent, good, fair, poor, and abysmal.

According to the above content, an image recognition evaluation table is constructed, as shown in Table 4. Then, sixty design students, designers, and non-design professionals in related industries were randomly invited to evaluate the images in the *Group a* and the *Group b*, and calculate the corresponding comprehensive evaluation value. Take a set of contrast patterns as an example; the evaluation results are shown in Table 4.

Test1	*Evaluation indicators*	Excellent	*Good*	*Fair*	*Poor*	*Abysmal*
	*f1*	28	20	8	4	0
	f2	28	16	12	4	0
	f3	4	24	16	8	8

Test2	*Evaluation indicators*	Excellent	*Good*	*Fair*	*Poor*	*Abysmal*
	*f1*	16	24	20	0	0
	f2	16	24	16	4	0
	f3	20	28	12	0	0

Table 4: The image recognition evaluation table.

The picture in Test1 is adjusted by the Auto Contrast Command in Photoshop2021, and the picture in Test2 is enhanced by the proposed algorithm in this paper. According to Table 4, the fuzzy judgment matrices M_1 and M_2 of the two pictures are obtained as

$$M_1 = \begin{bmatrix} 0.47 & 0.33 & 0.13 & 0.07 & 0 \\ 0.47 & 0.37 & 0.20 & 0.07 & 0 \\ 0.07 & 0.40 & 0.27 & 0.13 & 0.13 \end{bmatrix}, \quad M_2 = \begin{bmatrix} 0.27 & 0.40 & 0.33 & 0 & 0 \\ 0.27 & 0.40 & 0.27 & 0.07 & 0 \\ 0.33 & 0.47 & 0.20 & 0 & 0 \end{bmatrix}$$

From this, the comprehensive evaluation values B_1 and B_2 of the two images can be obtained as

$$B_1 = W \times M_1 = \left(0.35, 0.15, 0.50\right) \times \begin{bmatrix} 0.47 & 0.33 & 0.13 & 0.07 & 0 \\ 0.47 & 0.37 & 0.20 & 0.07 & 0 \\ 0.07 & 0.40 & 0.27 & 0.13 & 0.13 \end{bmatrix}$$

$$= \left(0.27, 0.36, 0.21, 0.10, 0.07\right)$$

$$B_2 = W \times M_2 = \left(0.35, 0.15, 0.50\right) \times \begin{bmatrix} 0.27 & 0.40 & 0.33 & 0 & 0 \\ 0.27 & 0.40 & 0.27 & 0.07 & 0 \\ 0.33 & 0.47 & 0.20 & 0 & 0 \end{bmatrix}$$

$$= \left(0.30, 0.43, 0.26, 0.01, 0\right)$$

For the evaluation of the above control group, the following results were obtained: for the image recognition evaluation of Test 1, 27% of the people thought it was excellent, 36% thought it was good, 21% thought it was fair, and 10% of the people thought it was bad, 7% thought it was abysmal. For the image recognition evaluation of Test 2, 30% of the people thought it was excellent, 43% thought it was good, 26% thought it was fair, 1% thought it was poor, and no one thought it was abysmal. We selected six groups of control pictures for evaluation, and the results are shown in Table 5 (Operational error is less than or equal to 0.01).

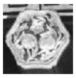
		a		*b*
1		(0.27,0.36,0.21,0.10,0.07)		(0.30,0.43,0.26,0.01,0)
2		(0.12,0.41,0.31,0.16,0)		(0.32,0.41,0.22,0.05,0)
3		(0.13,0.24,0.48,0.15,0)		(0.20,0.64,0.13,0.02,0)
4		(0.11,0.24,0.59,0.06,0)		(0.18,0.68,0.12,0.02,0)
5		(0.08,0.12,0.50,0.23,0.07)		(0.20,0.47,0.33,0,0)
6		(0.13,0.48,0.32,0,0.07)		(0.11,0.58,0.31,0,0)

Table 5: The fuzzy comprehensive evaluation results.

The images in *group a* are the results of the Auto-Contrast command in Photoshop2021, and *group b* are the results of the proposed algorithm enhancement.

According to the data in Table 5, the image enhancement method proposed in this paper not only enhances the edge recognition of the image but also optimizes the detail presentation of the pattern, which significantly enhances the recognition degree of the pattern by the human eye. in addition, the image optimization effect of this method is also significantly better than that of Photoshop2021 Auto-Contrast command. However, when the pattern color in the picture is similar to the background color, the enhancement effect of this method is weak, as shown in the evaluation results of the No.6 group of pictures in Table 5.

At the same time, we use MATLAB2020a to evaluate the structural similarity of the two sets of images based on SSIM (structural similarity). The data obtained are shown in Table 6.

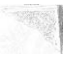
Group	*1*	*2*	*3*	*4*	*5*	*6*
a	 0.9566	 0.9272	 0.7801	 0.7187	 0.9358	 0.9136
b	 0.9473	 0.9301	 0.7818	 0.7324	 0.9470	 0.9342

Table 6: Image average structural similarity index.

According to Tab.6, except for No.1, the MSSIM values of *group b* are higher than *group a*. The closer the value is to 1, the better the image quality is. In most cases, this method can effectively improve the image quality.

3.2 Standardized Correction and Extraction of Patterns

This section needs to be done manually, relying on the visual recognition ability of the extractor, and proposes a method of using geometric auxiliary lines to locate and extract details of patterns in images.

Using the vector graphics tool Illustrator to draw auxiliary lines according to the composition of different patterns, the smoothness of the lines, and the integrity of the patterns, standardize and correct the patterns on the enhanced image, and extract the patterns by vectorization. Pattern standardized correction and extraction are mainly divided into five steps.

Step 1: Input the enhanced image into Adobe Illustrator;

Step 2: Draw structural auxiliary lines according to the formal features of the pattern in the image to determine the position and basic structure of the pattern;

Step 3: Combine the basic structure of the pattern and, according to the edge or outline shape of the pattern, draw the geometric auxiliary lines for extracting the details of the pattern;

Step 4: Use the pathfinder tool in Illustrator to cut and connect the auxiliary lines, and draw irregular graphics to obtain the pattern line draft;

Step 5: Use black and white to color the pattern to make distinctions, and then output the patterns vector files. As shown in Figure 5.

Figure 5: Workflow of pattern standardized correction and extraction.

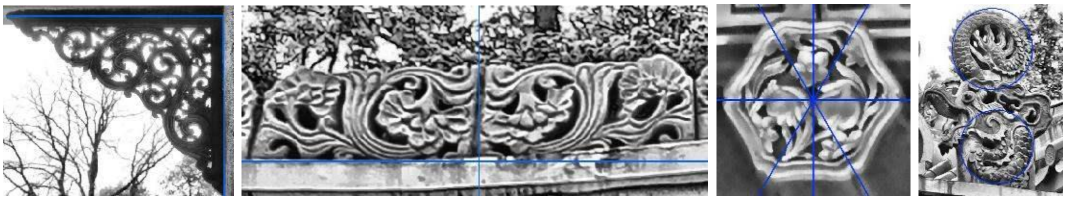
3.2.1 Drawing of Auxiliary Lines

The pattern standardized correction part mainly draws corresponding structural auxiliary lines and geometric auxiliary lines according to different pattern features to cut and connect the lines, to extract the complete pattern. This can maximize the smoothness of the pattern lines and repair the damaged pattern edges. What's more, the operation of this method is simple and easy to use, which reduces the difficulty of pattern extraction to a certain extent.

The structural auxiliary lines are mainly straight lines, which can effectively assist the extraction personnel in locating the patterns in the image, and are the basic skeleton of the patterns. The drawing of the structural auxiliary line is carried out according to the formal characteristics of the pattern (see Tab.2 for pattern form features), which mainly includes three structures: axial symmetry, central symmetry and rotational symmetry. As shown in Figure 6.

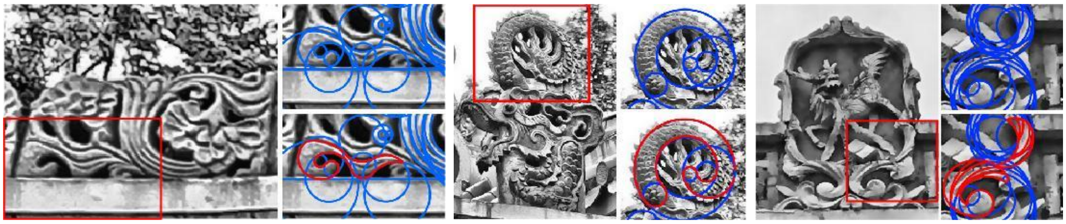
The patterns included in Figure 6 (a)(b)(c) are regular patterns, and all have specific rules. For those patterns, straight lines are used to locate the patterns. However, Figure 6 (d) is an irregular pattern with many curves, and circular auxiliary lines are used to locate the patterns.

The geometric auxiliary lines are mainly circles, and there are also a tiny number of geometries such as triangles and rectangles. They are used primarily to do standardized correction and some restorations of flaws caused by pictures' shooting angle, weathering and corrosion of architectural decorations, artificial damage, and handmade flaws. Repairs include extracting the details of the patterns, optimizing the curves' smoothness, and completing the defective parts of the patterns. The extractor needs to select the appropriate geometric auxiliary line according to the line curvature of the patterns' edges or the outline shape. As shown in Figure 7.



(a) (b) (c) (d)

Figure 6: Locating the pattern in the image by structural auxiliary lines.



(a) (b) (c)

Figure 7: Restorations by geometric auxiliary lines.

The patterns in Fig. 6(a)(b) have occlusion and deformation caused by the shooting angle, and the pattern in (c) has defects caused by weathering and corrosion. Drawing circular auxiliary lines according to the edges of the pattern and using the pathfinder tool in Illustration to cut and connect the curves to extract the pattern produces the line drafts of architectural decorative patterns.

3.2.2 Output of patterns vector files

To facilitate designers to innovate and commercialize traditional architectural decorative patterns systematically, it is necessary to output a unified pattern vector file.

According to the visual characteristics of the human eye[10], the pattern lines draft is colored with black and white color which is a high degree of recognition by the human eye to distinguish the main pattern and auxiliary pattern of the pattern, the foreground, and background, as well as the main body and details of the pattern. It has strong contrast and visual system, which is convenient for designers to use and promote digitally. Pattern samples are shown in Figure 8.

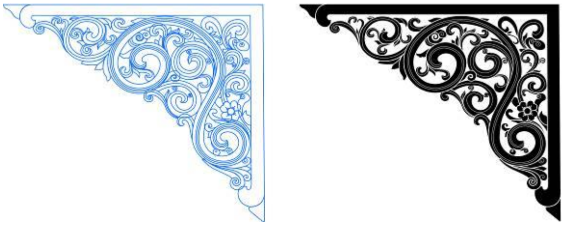


Figure 8: Vector processing of pattern.

4 RESULTS OF PATTERNS EXTRACTION

According to the analyses of the architectural decorative patterns of Yuelu Academy in the previous article (see Tables 1 and 2), image enhancement and pattern extraction are performed on typical samples (shown in Figure 2) according to the pattern extraction workflow proposed in this paper. The extraction process and results are shown in Table 7.

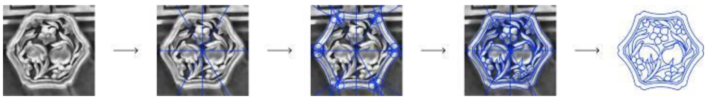
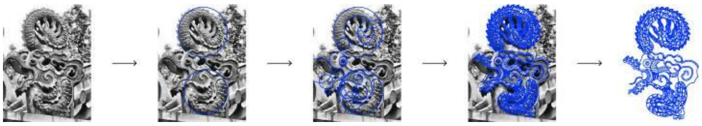
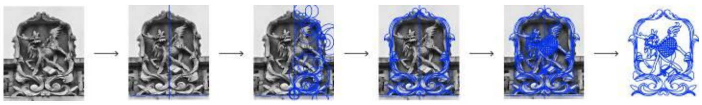
Figure Number	*Extraction Process*	*Results*
(a)		
(b)		
(c)		
(d)		
(e)		
(f)		
(g)		

Table 7: The extraction process and results of typical samples.

According to the above results, the workflow can effectively extract patterns from image materials and standardize them. And regardless of image quality, full and standard patterns can be extracted.

For the extraction process, the operator is required to master the four basic operations of Adobe Illustrator: the pen tool, the pathfinder command, the transformation command, and the line segment connection command. In order to elaborate the impact of Adobe Illustrator's personal skills on the workflow, we invited 2 people (T1, T2) who didn't know how to operate Adobe Illustrator and 2 people who are proficient in Illustrator (T3, T4) for testing. The test process is divided into 3 parts. First, the participants will be introduced to the basic functions of Illustrator and familiarized with the operation. Then, give the participants 3 selected images with difficulty from simple to difficult, and ask them to extract the patterns without method restrictions (the First

Extraction), recording the extraction results and the corresponding time. Finally, play the operation video of the extraction process proposed in this paper for the participants, and let them use this method to extract again (the Second Extraction), recording the extraction results and the corresponding time. In order to reduce test time, special-shaped patterns are not extracted, and the results are shown in Table 8.

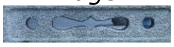
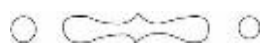
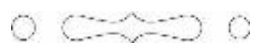
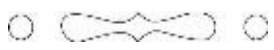
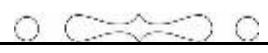
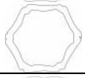
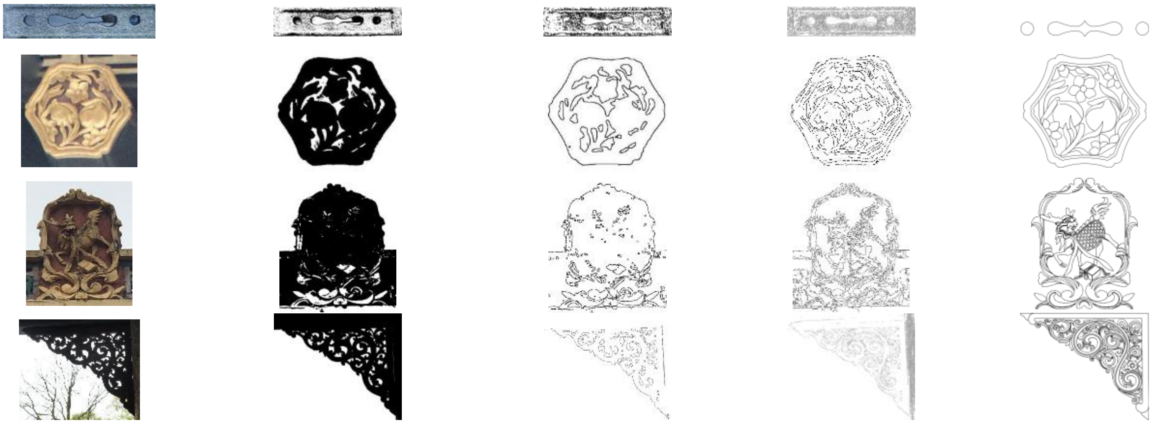
	Participants	*The First Extraction*	*Time*	*the Second Extraction*	*Time*
Image1 	*T1*		1′59″		6′27″
	T2		2′		10′
	T3		1′		2′43″
	T4		1′37″		3′
	Participants	*The First Extraction*	*Time*	*the Second Extraction*	*Time*
Image2 	*T1*		3′47″		13′59″
	T2		3′23″		9′31″
	T3		2′		8′22″
	T4		2′27″		7′05″
	Participants	*The First Extraction*	*Time*	*the Second Extraction*	*Time*
Image3 	*T1*		12′46″		1:50′56″
	T2		13′		40′
	T3		15′34″		33′52″
	T4		13′54″		43′37″

Table 8: Adobe Illustrator operational test results

According to the test results, using the workflow proposed in this paper for pattern extraction, even people who do not know how to use Adobe Illustrator can complete the pattern extraction task more comprehensive and standardized manner. However, comparing the time of the subjects T1/T2 and the subjects T3/T4, the personal skill significantly impacts the extraction efficiency. With the increase in the number of extraction patterns, the subjects will become more skilled, and the extraction time will be shorter and shorter. In addition, according to the test results, it is found that the basic structure of the patterns extracted by different subjects is consistent. Still, specific differences in subjective recognition and software operations cause the differences in pattern details. In the follow-up research, this part needs to be optimized to avoid the situation where the digital pattern cannot match the original image.

At the end of this paper, we compared the results from the proposed method with those from previous methods, as shown in figure 9. The patterns extracted entirely by computer image technology have a faster processing speed. Still, the results are not good, and the lines of the patterns are rough and lack details. And due to the limitation of the original image, the patterns extracted by the previous method are not standardized, which is not conducive to the digital archive and reuse of traditional patterns.



Input (a) (b) (c) (d)

Figure 9: Comparison of results from different extraction methods.

Figure 9(a) shows the results extracted by the OTSU algorithm proposed in the paper[4]; (b) are the results using the morphological algorithm combined with the Canny algorithm, which is offered in the article[5]; (c) are the results obtained by using the image enhancement method proposed in this paper combined with the Canny algorithm;(d) are the results extracted by the workflow presented in this paper. As we can see, the methods provided in references [4] and [5] have a good extraction effect on images with distinct patterns and backgrounds. Still, they lose a large part of the pattern details, which are not conducive to digitizing complex decorative architectural patterns. Comparing the two sets of results (b) and (c), after the image enhancement mentioned in this paper, the computer can identify and extract more pattern details, proving that the proposed image enhancement method can effectively improve the sharpness of the pattern edges in the image. In group (d), the workflow proposed in this paper can completely extract the patterns in the images. At the same time, the outlines of the patterns are corrected, the pattern details are optimized, and the defects caused by external factors such as weathering and corrosion are repaired to obtain a standardized digital file of the pattern.

This workflow provides new ideas for extractors and designers regarding cultural heritage protection and digitizing traditional patterns. At the same time, many vector files have been organized to form a material library of architectural decoration patterns of Yuelu Academy, which can provide standard material support and inspiration sources for the creativity and productization of the academy of classical learning's culture.

5 CONCLUSION AND FUTURE DIRECTIONS

This paper proposes a workflow for extracting decorative architectural patterns based on image enhancement technology and computer-aided design tools, including image enhancement and pattern standardization correction and extraction. The extraction results of typical pattern samples show that this workflow can batch enhance architectural decoration image materials, enhance their recognition and extract standard patterns. To a certain extent, this workflow can effectively reduce the equipment and material sampling environment requirements for the on-site acquisition of decorative architectural patterns and improve the availability of original materials. On this basis, geometric auxiliary lines can quickly locate the patterns in the image and reduce the difficulty of detail extraction. The features and innovations of this research are as follows: (1) A systematic, standardized, and efficient workflow based on computer-aided design technology is proposed for the problem of insufficient systematisms and low efficiency in the extraction of decorative architectural patterns. The innovative application of the CLAHE algorithm and adaptive bilateral filtering optimizes the problems of inefficiency and limited expertise produced by using PS to preprocess images. At the same time, it is proposed to use computer-aided design tools to draw geometric auxiliary lines for standardized correction and extraction of patterns, which significantly reduces the time cost and difficulty of pattern extraction. (2) This process simplifies the work of pattern extraction to drawing, cutting, and connecting simple geometric auxiliary lines, which breaks the limitation of professional ability. Even non-design researchers can quickly get started and perform pattern extraction. In addition, this pattern standardization extraction process is universal and applies to the digitization of all complex traditional patterns.

At present, this workflow still requires manual participation. In future research, researchers can try to realize automatic pattern extraction through edge recognition, curve fitting, machine learning, and other technologies based on the auxiliary line extraction method proposed in this paper.

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