

Article

Experimental Study and Effectiveness Evaluation on the Rapid Antiquing of Red Sandstone in Ancient Buildings Restoration

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Abstract: As there are few cases of red sandstone rapid antiquing in ancient buildings and as it is difficult to reproduce, this paper carried out an experimental study and effect evaluation assessment on red sandstone rapid antiquing in the restoration of ancient buildings, based on a restoration project of an ancient town in Ganzhou. The method and the implementation process of red sandstone rapid antiquing are proposed by starting from color antiquing and texture antiquing. By controlling the concentration of red mud, grass ash, and carbon black in color coatings as variables, using the HSV (hue, saturation, value) color space and Tamura texture features (roughness, contrast, orientation) to quantitatively analyze the antiquing effect, an analytical model for evaluating the red sandstone antiquing effect based on image processing was established. The results showed that among all the antiquing groups, the group that used white cement, green zeolite, imitation greenery, red clay, grass ash, and 5 mL/L carbon black liquid at the same time had the best effect, with a qualified rate of 90%. The analytical model can improve the evaluation efficiency of red sandstone antiquing and avoid errors caused by subjective factors. With feasibility and practicability, the model is conducive for new red sandstone to meet the requirements of ancient building restoration through rapid antiquing. It provides a scientific basis and technical reference for red sandstone antiquing in stone cultural relics and ancient building restoration.

Keywords: ancient buildings restoration; red sandstone; rapid antiquing; image processing; effect evaluation



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1. Introduction

China is an ancient civilization with thousands of years of history and has preserved a rich and varied collection of ancient buildings, which are not only a precious treasure for all mankind but also witness the evolution of the Chinese nation for five thousand years. Regrettably, subject to human or natural factors, many ancient buildings have suffered varying degrees of damage under the erosion of time and even face the threat of destruction. Protecting cultural relics is to protect the cohesion and centripetal force of a country, as well as to be highly responsible for the history [1]. South China preserves lots of ancient buildings with red sandstone as their main body, which have extremely important historical significance. However, with a relatively loose structure, the red sandstone is poor in weathering resistance. After years of destruction and erosion, the weathering disease is becoming more and more serious. The current situation is worth worrying about [2,3]. Therefore, attention should be paid to the restoration of red sandstone used in ancient buildings.

Most of the red sandstone buildings are exposed to the weathering environment in nature, especially with the development of modern industry, with environmental pollution and acid rain causing more serious erosion to the stone relics and monuments [4,5]. Improving the environment is an effective way to control the lesions of red sandstone buildings, but eliminating the current environmental pollution cannot be achieved overnight. It is inappropriate to carry out drastic refurbishment to ancient buildings with profound cultural

value and dense historical heritage [6]. Therefore, using the same materials as the existing ancient buildings for repair and reinforcement is one of the feasible restoration methods.

In this regard, Mr. Liang Sicheng proposed that the renewal and renovation of ancient buildings should be based on repair and maintenance as early as 1935, and it should uphold the principle of “Repair It as Old”, which was of landmark significance for China’s architectural renewal and renovation [7]. The concept of “Repair It as Old” is closely related to the Western “Authenticity” and “Scientific Restoration Concept”. After renewal and renovation, the ancient buildings not only retain their historical appearance, cultural vicissitudes, and architectural structure but also have modern functions and durability [8]. China’s 2015 revised “Guidelines for the Protection of Cultural Relics and Monuments in China” also stipulated that the protection of ancient buildings should follow the principles of “no Change to the Original State”, “Authenticity”, “Integrity”, “Minimum Intervention”, “Protection of Cultural Traditions”, “Use of Appropriate Protection Techniques” and “Disaster Prevention and Mitigation” [9]. Antiquing the red sandstone used for new restoration can adhere to the principle of “Repair It as Old”, which could make the newly restored red sandstone components appear closer and similar to the original parts remaining on the old buildings, so as to achieve overall harmony and beauty.

However, there is no strict operational definition of this principle. Satisfactory results can only be achieved through repeated attempts and experience of craftsmen. In the process of ancient building restoration, it is necessary to use newly purchased red sandstone as stone for restoration and reconstruction. However, there are great differences between the old and new red sandstone components in appearance, color, and weathering degree, which seriously affect the overall harmony and local aesthetics of the restored building [10]. There are also difficulties for the antiquing of red sandstone in ancient buildings. First of all, the red sandstone’s antiquing in ancient buildings is different from the cultural relic restoration. Cultural relic restoration is ultimately similar to the fresco, which is the structure of the final restoration while the ancient building restoration is mostly the wall, which is the repair of missing parts of appearance [11,12]. Its surface structure, crack, and concave and convex sense do not have a uniform shape, therefore, when antiquing ancient buildings, it is not only necessary to be similar in style and texture but also to achieve a sense of irregularity of “Like but not the Same”, which is exactly the difficulty for rapid antiquing in ancient buildings [13,14]. Second, as the current red sandstone’s antiquing technology is not mature, there is no strict set of standards for the antiquing process, and even the use of red sandstone for antiquing is relatively low. There are only antiquing methods on similar stone, wood, or porcelain antiques, etc., that can be referred to [15–17]. Finally, some of the existing antiquing methods have a long period of realization, such as the soil burial method for reproducing the sense of rock obsolescence, moss cultivation on the rock surface for restoring the traces of vegetation [18], etc. Although these methods are closer to the deterioration of rocks under natural conditions, they usually require continuous design, practice, and comparison during antiquing with a long period and high cost. At present, there is still a lack of relevant research on rapid antiquing.

In addition, the antiquing effect of red sandstone in ancient buildings needs to be evaluated. However, it is difficult to quantify the evaluation of its antiquing visual effect, which mostly relies on expert experience and human visual evaluation. Although expert evaluation is authoritative to a certain extent, it also has major drawbacks as there are differences in human perception and subjective influencing factors [19]. Therefore, the adoption of expert assessment sometimes cannot be fully convincing for the public and it is more time-consuming, labor-intensive, and poor in economy and applicability.

Aiming at the technical difficulties existing in red sandstone rapid antiquing and the shortcomings of the evaluation methods, this paper carries out an in-depth experimental study and effect evaluation on red sandstone rapid antiquing in the restoration of ancient buildings, relying on the construction project of an ancient town in Ganzhou, Jiangxi Province. Starting from the color and texture, it presents the red sandstone rapid antiquing method and implementation process. The best method of antiquing can be selected by

setting up control experiments with controlled variables. With a short operation cycle and good effect, red sandstone rapid antiquing in ancient buildings can be realized, which makes up for the shortcomings of the long cycle of ordinary antiquing methods and fills the vacancy in the research of red sandstone antiquing methods in buildings. At the same time, to avoid the errors caused by personal subjective factors, the model and method for evaluating red sandstone rapid antiquing based on HSV color space and Tamura texture features are proposed. This evaluation method can quantify the antiquing effect and realize quantitative analysis, which can not only reduce the errors caused by individual subjective evaluation but also improve the evaluation accuracy and efficiency of red sandstone antiquing. This paper provides a theoretical basis and technical support for red sandstone antiquing in the restoration of stone relics and ancient buildings.

The sampling location and sample appearance of the original red sandstone are shown in Figure 1.



Figure 1. (a) Sampling location; (b) sample appearance of original red sandstone.

2. Materials and Methods

To obtain a satisfactory antiquing effect, an experimental study and effectiveness evaluation on the red sandstone rapid antiquing in ancient building restoration was carried out. Figure 2 shows the core framework and technological roadmap, which primarily involves pre-analysis, the antiquing process, and the evaluation system. The general program includes the following:

- (1) Analyze the state and appearance of the red sandstone in the original ancient buildings to learn about its color and texture features, so as to determine the materials and parameters required for antiquing.
- (2) Compare the antiquing material to the original red sandstone by using RGB color space, then calculate the ratio of the material, and determine the process and experimental program.
- (3) Use HSV color space and Tamura texture features to evaluate comprehensively the effect of red sandstone rapid antiquing. Quantify the antiquing effect by using the statistical features of similarity between the antiquing red sandstone and the original red sandstone, evaluate the effectiveness of each scheme, and choose the optimum antiquing scheme.

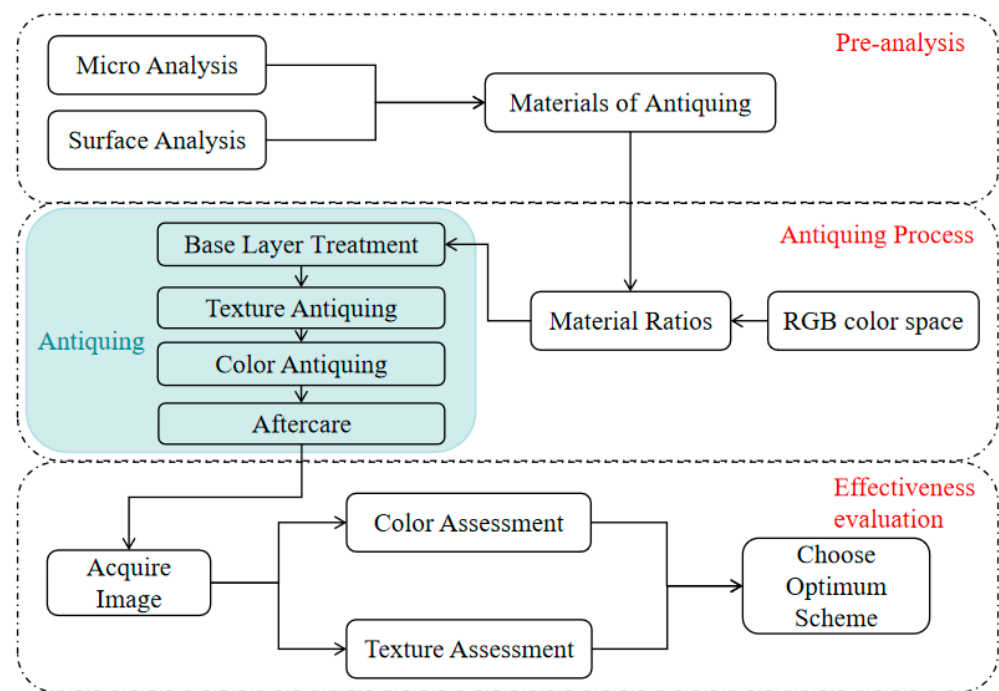


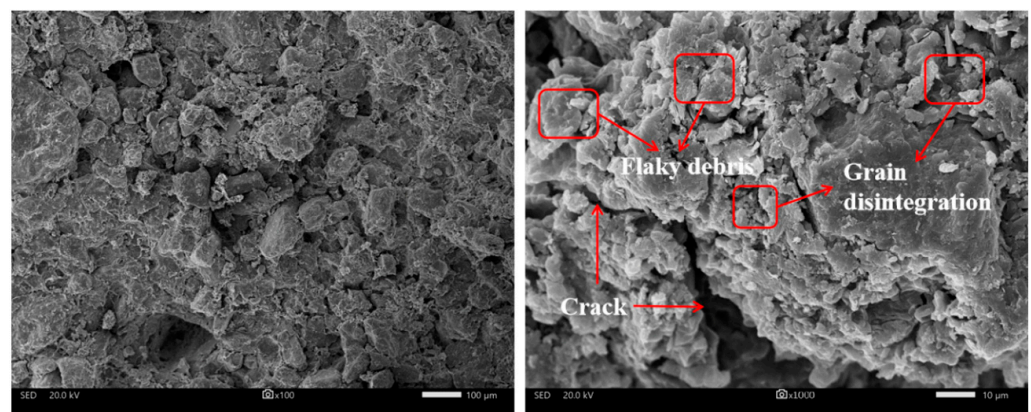
Figure 2. Technology roadmap.

2.1. Pre-Analysis and the Selection of Antiquing Materials

Pre-analysis, including on-site investigation, on-site sampling, literature review and analysis, as well as some microscopic detection experiments was carried out to analyze the state and appearance of the red sandstone in the original ancient buildings, providing a basis for the subsequent work of antiquing.

The ancient town is located in the Gongjiang River, near Ganzhou City's eastern suburb. It is always wet and humid, which is suitable for the growth of moss plants. Therefore, the red sandstone in the ancient buildings is more likely to be damaged. Furthermore, there is acid rain precipitation within the area, which causes an acid corrosion effect on the red sandstone, resulting in a rough, pitted, and irregular textured surface [20]. Meanwhile, there are other influencing factors, such as high temperature, dry-wet cycle, and anthropogenic damage, which can also cause red sandstone damage [5].

The examined images from the original red sandstone rock samples for EMS and XRD examination are presented, respectively, in Figures 3 and 4.



Part 1 (×100 and ×1000)

Figure 3. SEM image of original red sandstone.

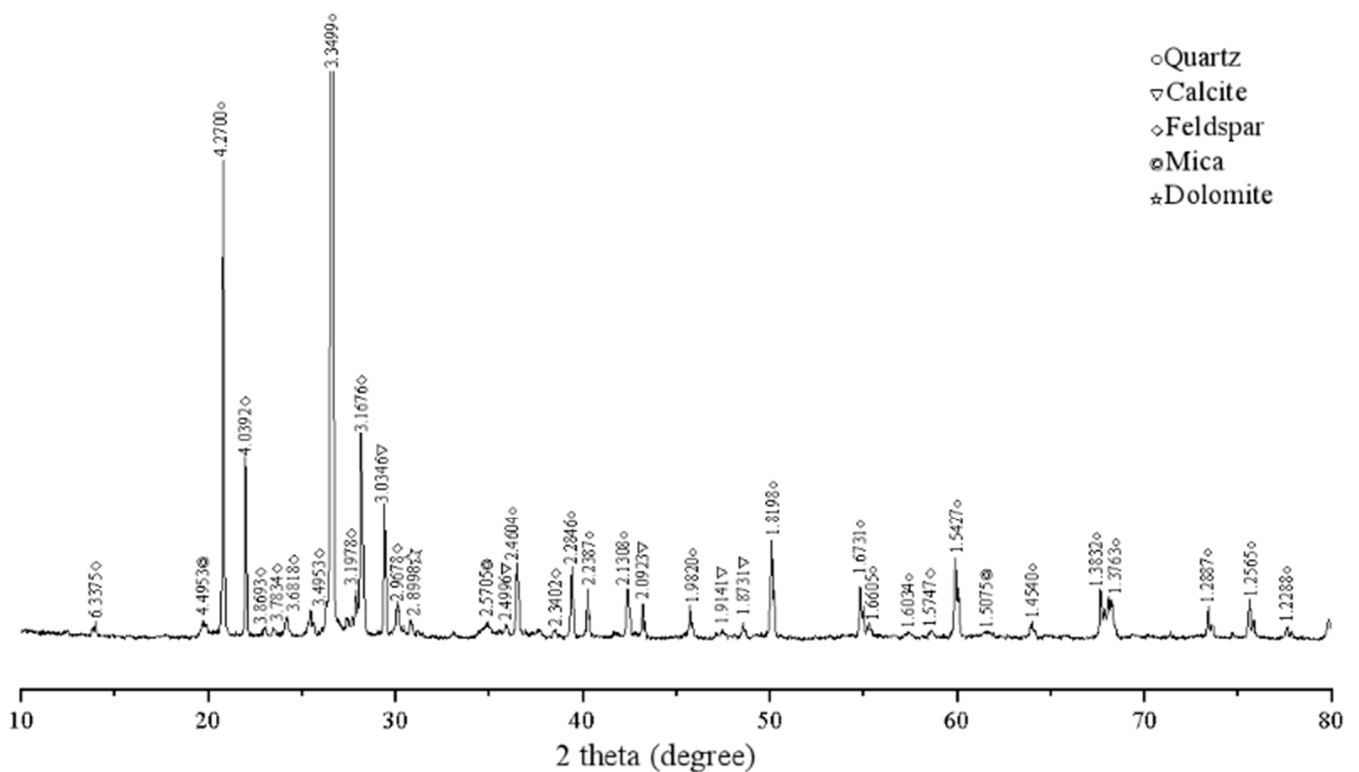


Figure 4. XRD image of original red sandstone.

From the microscopic detection and analysis, we can find that the surface of the original red sandstone is seriously infringed. The interior has developed into a variety of cracks and defects, accompanied by the generation of new material called dolomite. Due to the increase in the number of pores and cracks, its strength has begun to be damaged. As a result, it needs to be repaired.

Photographs of the red sandstone rock samples at the site are shown in Figure 5.

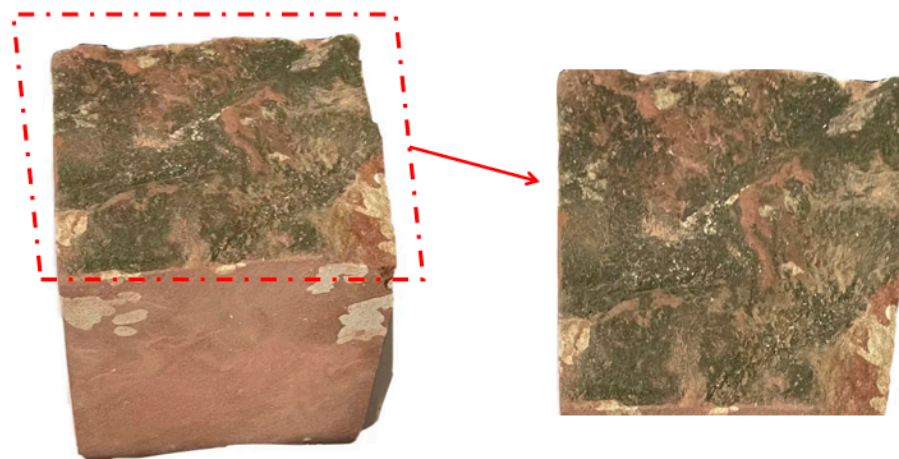


Figure 5. Image of original red sandstone specimen.

Based on the macroscopic analysis of the red sandstone samples taken from the site, it can be found that the surface of the red sandstone in the original ancient buildings presents a gully and horizontal texture, and the distribution of texture and color is irregular due to the long-term erosion, the growth of moss plants, and the accumulation of biological remains. Using visualization software (avizo 2019) to analyze the image of the original

red sandstone in ancient buildings, the result shows that the surface texture accounts for 40–60%, with convex and convex defects ranging from 0–8 mm.

Based on the above analysis results, the following five kinds of antiquing materials to carry out the rapid antiquing research on ancient buildings with red sandstone were selected. The antiquing principles and functions are as follows.

(1) White cement: the white pigment or ingredient contained therein covers the surface of red sandstone to give it a whiter appearance, which can replicate the whiteness caused by long-term erosion, compared with other materials; its color is purer and has a stronger covering power. (2) Red clay: its color is similar to that of red sandstone and contains iron oxides and other components, which can be used to adjust the overall tone of red sandstone after oxidation to make it more uniform. (3) Grass ash: its gray color and grain can simulate the ancient sense of red sandstone buried in the soil for a long time, which increases the sense of history and texture of red sandstone; also, it is more in accord with the characteristics of the soil. (4) Green zeolite and imitation greenery: they are used to simulate the greenish-black spots caused by moss plants covering the red sandstone for a long period. Their color and grain can simulate the growth of plants and increase the natural sense of the red sandstone surface. (5) Carbon black: it is used to restore the sense of “stain” formed by long-term outdoor weathering of red sandstone with great simulation effects and stable performance characteristics.

From the study of the chemical properties and reactions between the antiquing materials and the red sandstone, it can be found that red sandstone is a sedimentary rock composed of iron oxide and other minerals; green zeolite is a mineral rich in aluminum, silicon, calcium, and other components; imitation greenery is made of a variety of stable synthetic materials; grass ash is mainly composed of calcium carbonate, calcium oxide, and potassium oxide, and red clay is mainly composed of iron oxide and other clay minerals. These substances do not have significant chemical reactions with red sandstone under natural conditions.

White cement is mainly composed of calcium oxide and silicate, which may chemically react with red sandstone to produce calcification in the case of moisture or water immersion. However, the calcification of red sandstone can increase its density and hardness, which can improve the physical properties of the rock and make it more solid and durable.

The antiquing materials are shown in Figure 6.



Figure 6. Antiquing raw materials.

2.2. Material Proportioning and Process Flow Implementation

Since there are no relevant norms or standards on determining the proportion of paint materials, a pre-analysis using the RGB color space to compare the similarity of different materials to the original red sandstone image was performed. The result shows that the similarity between red clay, grass ash, green zeolite, imitation greenery, and the original image are approximately 0.29, 0.33, 0.25, and 0.15. Several pre-tests were conducted in accordance with this theoretical range, and the finalized ratio of white cement, red clay, grass ash, green zeolite, and imitation greenery was 1:1:1:2:0.5.

The previous section used visualization software (avizo 2019) and microscopic detection to pre-analyze the original red sandstone. The red sandstone in ancient buildings is antiqued from the two aspects of image texture and image color [21–26] in this section.

The specific antiquing process is as follows. The flow chart of red sandstone antiquing process is shown in Figure 7.

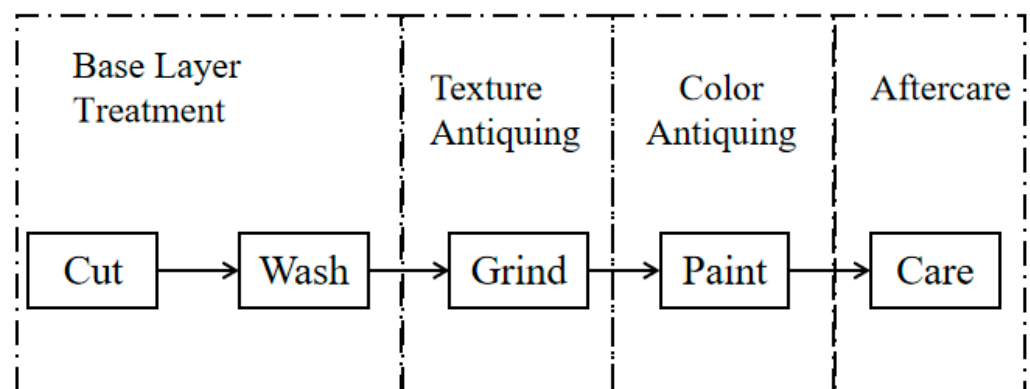


Figure 7. Flow chart of the process of antiquing red sandstone.

(1) Select the red sandstone samples as far as possible that are similar to the original one but with better performance. Cut them into appropriate sizes and clean the surface with a water gun to prevent floating soil and dust from interfering with the penetration of the subsequent antiquing paint, ensuring the antiquing effect.

(2) According to the pre-analysis of the texture ratio and defect range, use the carving machine to grind the surface of red sandstone, so that it has a certain sense of convexity and roughness to achieve the purpose of texture antiquing.

(3) Use various kinds of soil materials in a certain proportion as the antiquing materials and paint them on the ground surface of the red sandstone. After 48 h, use a steel brush to clean the antiquing red sandstone and remove the unstable paint from the surface. Then use carbon black as the material for staining to provide the sense of antiquing. Perform a series of running water flushes on the sample surface after painting carbon black static for 24 h. This can strengthen the visual sense of “old” on the red sandstone to achieve the purpose of color antiquing.

(4) Place the antiqued red sandstone in the original environment (or simulated environment) for three days to ensure the stability of its materials. A protective material needs to be painted on the surface if long-term deterioration protection is required [27].

It should be noted here that white cement, green zeolite, imitation greenery, grass ash, and red clay are pre-mixed in proportion and then painted onto the surface. After the solidification and brushing, different concentrations of carbon black liquid should be painted and soaked onto each group of materials.

After antiquing, the original antiquing red sandstones are placed in the same light and at the same angle to produce the images, which are used in the subsequent evaluations to ensure the accuracy of the results.

2.3. Image Processing and Assessment Model

In order to solve the problem that the evaluation of antiquing effect is difficult to quantify and highly subjective, the method of image similarity was adopted to evaluate the antiquing effect, which is also considered to be a numerical representation of the similarity between two images in terms of visual content [28]. By extracting texture features and color features, an objective evaluation of the effect of red sandstone rapid antiquing can be carried out based on these two aspects. The evaluation is conducted at the data level and the results are quantitative and persuasive. In this way, a model can be established to objectively evaluate the effect of rapid antiquing. The steps of image feature extraction and antiquing effect evaluation are shown in Figure 8.

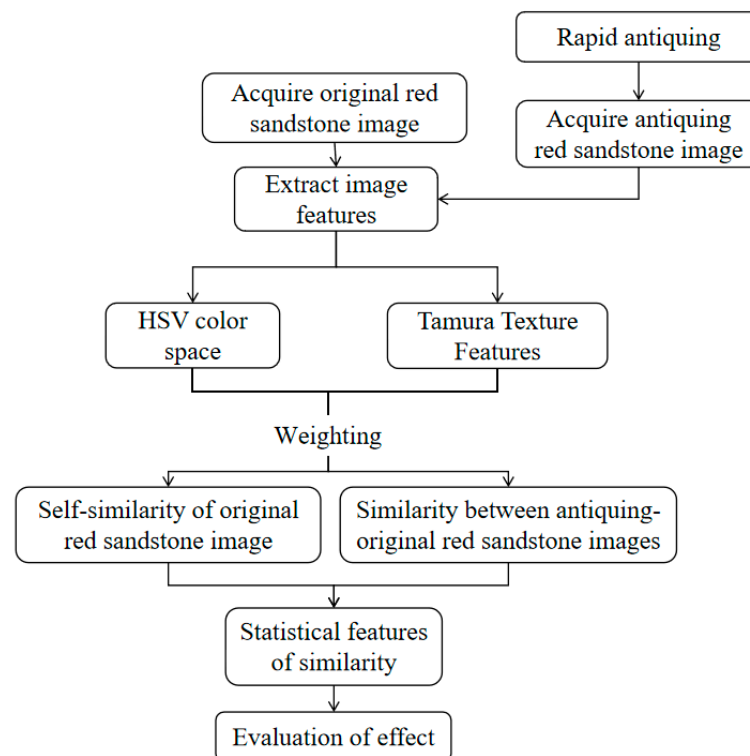


Figure 8. Flowchart of the model for evaluating the effect of antiquing.

Based on the red sandstone antiquing process and literature research, this paper chose to use the HSV color space and Tamura texture features to comprehensively evaluate the method of red sandstone rapid antiquing. To begin with, we use the HSV color space and the Tamura texture features to calculate the color similarity S_{col} and texture similarity S_{tex} , respectively, between the antiquing and original red sandstones. The weighting is then determined by objectively assigning weights to the two factors of color and texture, yielding the comprehensive similarity S :

$$S = \omega \times S_{col} + (1 - \omega) \times S_{tex} \quad (1)$$

At the same time, we take the self-similarity S_0 of the original old red sandstone as the similarity boundaries of the mode. By comparing S with S_0 , we can conclude that if $S > S_0$, the antiquing effect is qualified. We can assess the antiquing effect by calculating the statistical features of the similarity and the qualification rate.

S_0 is calculated as follows: use the ten original red sandstone images through two-two permutations and combinations to calculate the similarity S_{i-j} . To avoid repeated calculations and self-comparison of the same image, we specify that $i < j$ and create the similarity matrix according to this. The formula (2) calculates the average value of the

similarity matrix, which serves as the model's similarity boundaries S_0 . Self-similarity matrix of the original red sandstone is shown in Table 1.

$$S_0 = \frac{1}{C_2^n} \sum_{i=1}^n \sum_{j=i+1}^n P_{i-j} \quad (2)$$

where S_0 is the original red sandstone self-similarity, i is the rows of the matrix, j is the columns of the matrix, and n is the number of original red sandstone images.

Table 1. Self-similarity matrix of the original red sandstone.

	1	2		10
1		S_{1-2}		S_{1-10}
2				S_{2-10}
.....				S_{x-10}
10				

3. Experimental Procedure

In this paper, red sandstone samples were selected from Ganzhou locally and cut into new red sandstone blocks measuring 50 mm × 50 mm × 20 mm. They were divided into three large groups of nine teams of two pieces each, then the antiquing process was begun. Grass ash, red clay, and carbon black concentration were used as three variables in the color antiquing process, respectively, to compare how the variables affected the antiquing effect through the experiment. Complete set of antiquing experimental flowcharts is shown in Figure 9.

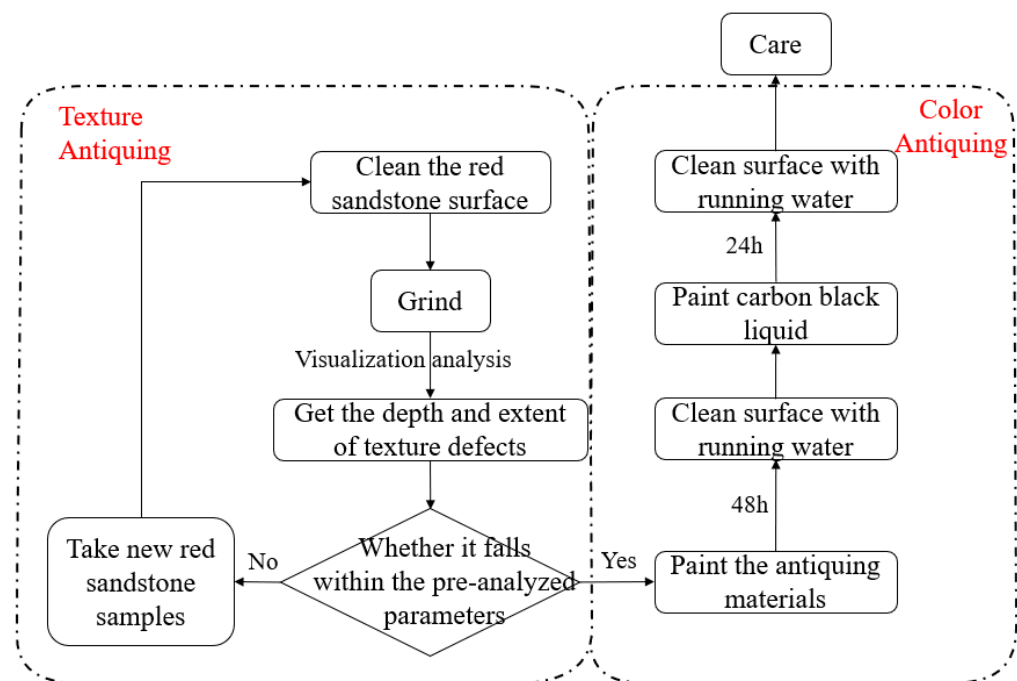


Figure 9. Complete set of antiquing experimental flowcharts.

(1) Texture antiquing.

According to the analysis in 2.1, it was found that the surface texture of the old red sandstone in the ancient buildings accounted for between 40–60%, and its surface unevenness defects ranged from 0–8 mm. We first used a carving machine to grind the newly made red sandstone. The carving machine adopts the Asgar Tools electric grinding gun, the product model is ASJ-17.

Each sample was ground with the carving machine imitating the texture of the original red sandstone at different positions, lasting approximately 3 s at the shallower parts and 10 s at the deeper parts with a rotational speed of 8000 r/min. To restore the irregular textural defects of the weathered red sandstone, the machine was equipped with a 200-mesh sandpaper ring, which is moderate and suitable for producing a texture without excessive abrasion on the surface. The speed of 8000 r/min is a medium speed for grinding, which provides a degree of rapidity while still maintaining a degree of control.

When grinding, it is necessary to pay attention to the direction and try to follow the original grain direction of the red sandstone to ensure that its structure will not be damaged and to minimize the risk of surface cracks and spalling. In addition, grinding in the direction of the original grain direction helps to maintain the stability of the rock.

After grinding, the image of the red sandstone was obtained for visual analysis. Then, a comparison was made to determine whether the defect depth and range of the red sandstone were within the above parameter after texture antiquing. If not, the new red sandstone sample should be taken to repeat the above steps until all parameters conform to the results of the defect range in the pre-analysis. Finally, nine groups of newly made red sandstone after texture antiquing were determined.

In addition to using visual analysis to quantify the depth and range parameters, data points can also be set to quantify the data accurately. Meanwhile, calculating the average depth, maximum depth, etc., of the grinding to ensure that the defect depth and range of the antiquing red sandstone are similar to the original one can also be considered.

The carving machine and the effect of grinded red sandstone are shown in Figure 10.

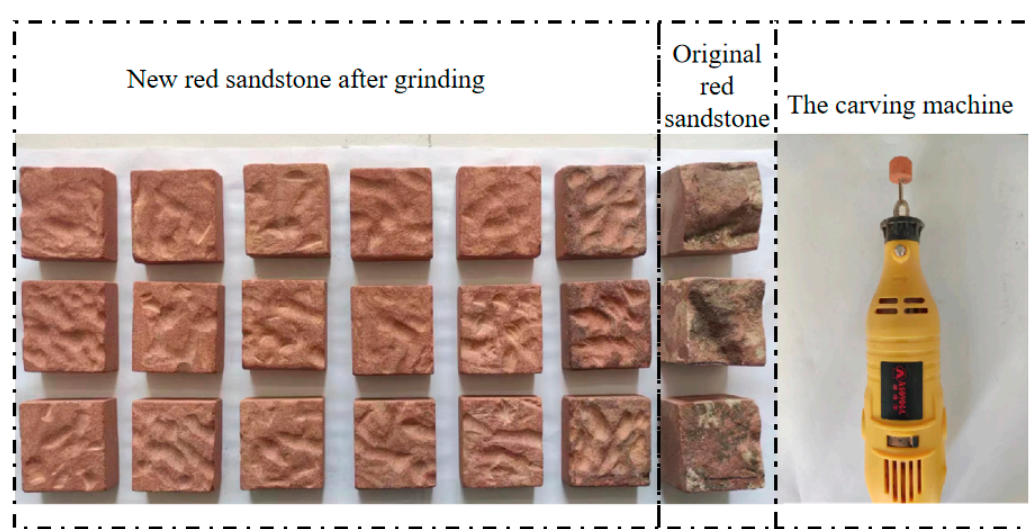


Figure 10. Grinding results and tools.

(2) Color antiquing.

Subsequently, according to the proportion of materials in Table 2, the materials were mixed with water and stirred until uniform and viscous, and then painted on the surface of the ground red sandstone. It needs to be ensured that the surface is free of debris before painting and the stone is in a state that is neither too wet nor too dry while painting.

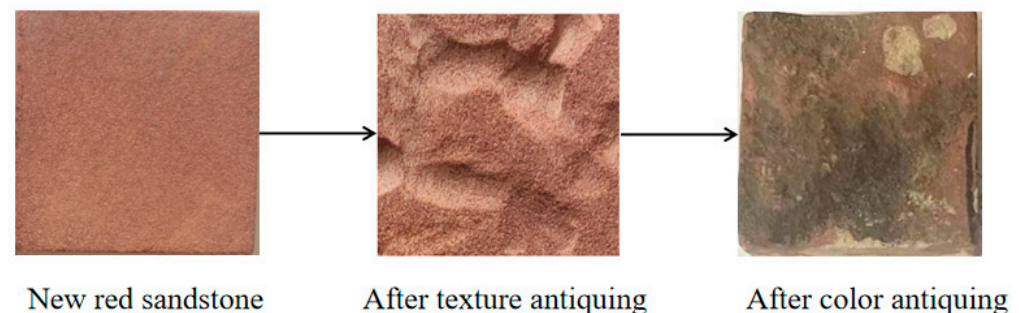
According to the antiquing process in Section 2.2, after 48 h, each piece of antiquing red sandstone was placed under water flow and cleaned with a steel brush for 60 s to remove excess paint on the surface. Then they were painted with 1 mL/L, 2 mL/L, and 5 mL/L concentration of carbon black liquor on the surface according to Table 2, respectively, for the appearance of stains to further strengthen the visual “old” appearance of antiquing red sandstone to achieve the full purpose of color antiquing.

Table 2. Proportion and concentration of antiquing materials.

Number	Materials	Antiquing Materials					
		White Cement	Green Zeolite	Imitation Greenery	Red Clay	Grass Ash	Carbon Black Liquid
Group 1	1-1	1	2	0.5	1	1	2 mL/L
	1-2						1 mL/L
	1-3						5 mL/L
Group 2	2-1	1	2	0.5	1		2 mL/L
	2-2						1 mL/L
	2-3						5 mL/L
Group 3	3-1	1	2	0.5			2 mL/L
	3-2						1 mL/L
	3-3						5 mL/L

After painting the carbon black liquor for 24 h, water flushing was repeated. Each piece of antiquing red sandstone needed to be cleaned under the water flow with a steel brush until the water flow was transparent without an obvious black solution, which indicated that the carbon black liquor on the surface had been washed clean.

The antiquing process can be completed in one week. The process not only ensures that the red sandstone material is finely treated, but it also significantly increases the efficiency of red sandstone antiquing. It can shorten the antiquing cycle for red sandstone and accelerate the construction process. Process of red sandstone antiquing is shown in Figure 11.

**Figure 11.** Process of red sandstone antiquing.

4. Results Analysis

4.1. Color Antiquing Analysis

HSV color space is a type of color space based on human visual perception, which divides colors into three components: hue, saturation, and value. Among them, hue indicates the type of color, saturation indicates the purity or concentration of the color, and brightness indicates the degree of lightness or darkness of the color. It is an extension of RGB. Compared with RGB color space, it is more in line with how the human eye perceives color, and it is widely used in image processing [29].

When processing red sandstone images, HSV is able to capture variations in different tones and saturation more accurately in red sandstone. Since red sandstone may contain multifarious tonal variations of red, orange, and brown, the HSV color space can better distinguish the subtle differences between these colors. Meanwhile, its saturation component can also better reflect the color saturation variations in red sandstone images, which can provide richer color information. Therefore, the HSV color space method was used here to analyze the color antiquing effect of red sandstone. Its schematic is shown in Figure 12.

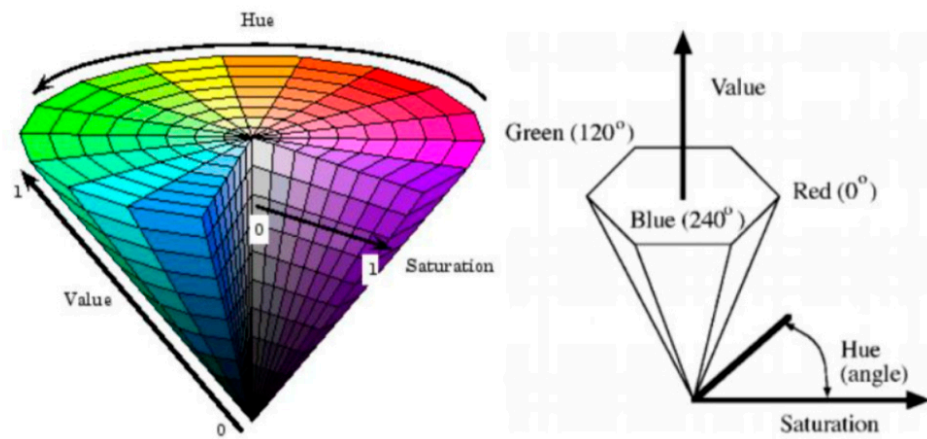


Figure 12. HSV color space schematic.

The color similarity calculation process used in this paper is as follows:

(1) Extract three features (r , g , b) of image 1 and image 2, respectively, transform them into three color features of HSV and calculate the histogram for each component denoted as H_{h1} , H_{s1} , H_{v1} , and H_{h2} , H_{s2} , H_{v2} .

(2) Calculate the cosine similarity of the three features.

$$\begin{aligned}\cos \theta_h &= \frac{\sum_{i=1}^{180} H_{h1}(i) \cdot H_{h2}(i)}{\sqrt{\sum_{i=1}^{180} H_{h1}(i)^2 \cdot \sum_{i=1}^{180} H_{h2}(i)^2}} \\ \cos \theta_s &= \frac{\sum_{i=1}^{256} H_{s1}(i) \cdot H_{s2}(i)}{\sqrt{\sum_{i=1}^{256} H_{s1}(i)^2 \cdot \sum_{i=1}^{256} H_{s2}(i)^2}} \\ \cos \theta_v &= \frac{\sum_{i=1}^{256} H_{v1}(i) \cdot H_{v2}(i)}{\sqrt{\sum_{i=1}^{256} H_{v1}(i)^2 \cdot \sum_{i=1}^{256} H_{v2}(i)^2}}\end{aligned}\quad (3)$$

(3) Apply the minimum normalization principle to calculate the similarity of each component.

$$\begin{aligned}S_{colh} &= \frac{\sum_{i=1}^{180} \min(H_{h1}(i), H_{h2}(i))}{\min(\sum_{i=1}^{180} H_{h1}(i), \sum_{i=1}^{180} H_{h2}(i))} \\ S_{cols} &= \frac{\sum_{i=1}^{256} \min(H_{s1}(i), H_{s2}(i))}{\min(\sum_{i=1}^{256} H_{s1}(i), \sum_{i=1}^{256} H_{s2}(i))} \\ S_{colv} &= \frac{\sum_{i=1}^{256} \min(H_{v1}(i), H_{v2}(i))}{\min(\sum_{i=1}^{256} H_{v1}(i), \sum_{i=1}^{256} H_{v2}(i))}\end{aligned}\quad (4)$$

(4) Take the average of the similarity of the three components as the overall color similarity of image 1 and image 2.

$$S_{col} = \frac{S_{colh} + S_{cols} + S_{colv}}{3}\quad (5)$$

The cosine similarity measures the degree of directional agreement between two histograms. The minimum normalization standardizes the similarity values to compare and interpret. Using the two steps described above, we can obtain a similarity value S_{col} ranging from 0 to 1. The closer this value is to 1, the greater the color similarity between the two images. The calculation process is depicted in Figure 13.

The 10 original red sandstone images obtained are compared two by two. According to Equation (2), we can calculate the color self-similarity $S_{0col} = 0.642$ for the original red sandstone.

Subsequently, nine groups of antiqued red sandstone images are sequentially compared with 10 original red sandstone images two by two. Each group of antiquing red sandstone contains two images, allowing for a total of 20 similarity values. Then we calculate the statistical features and qualification rate of the 20 similarity values for each group (refer to Table 3), compare and analyze the similarity values, and study the effect of color antiquing.

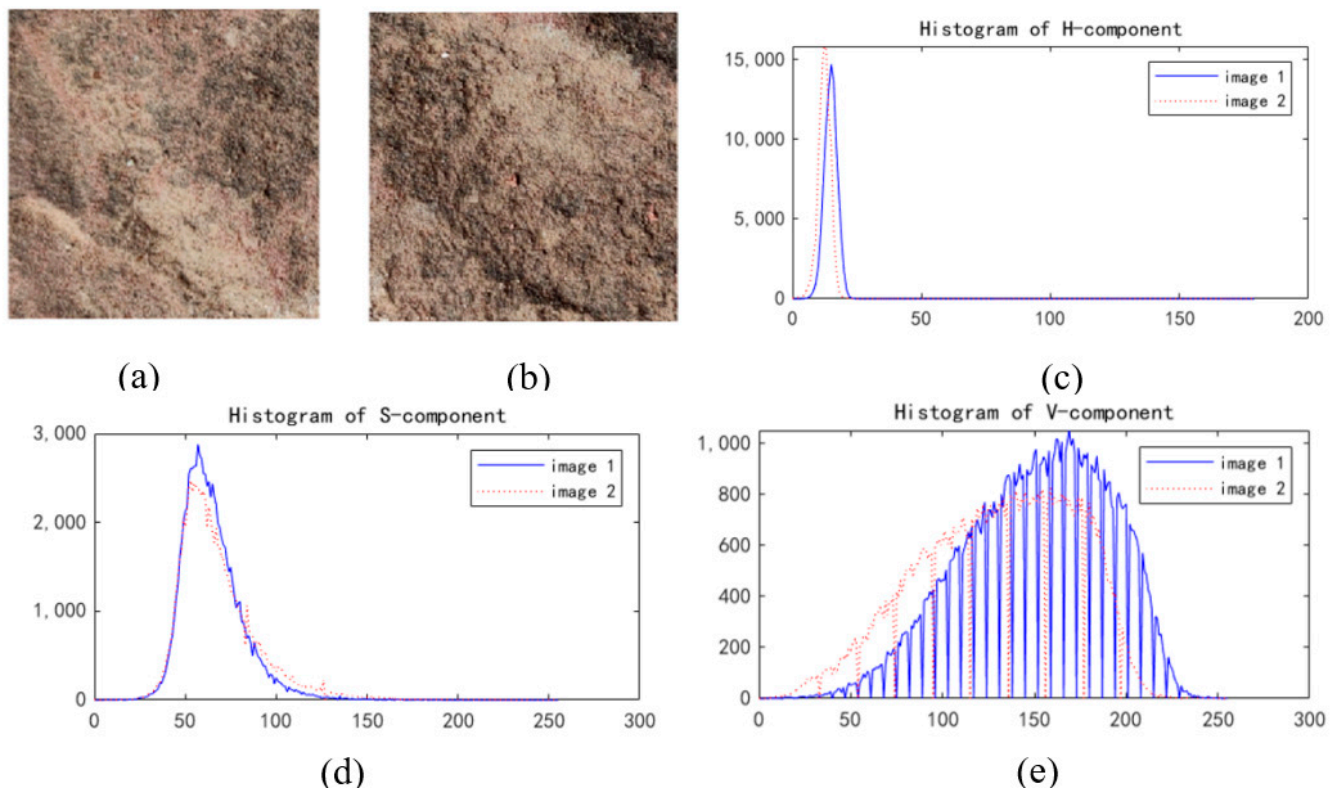


Figure 13. Calculation process diagram of color similarity of red sandstone image: (a) Image 1; (b) Image 2; (c) Histogram of H-component; (d) Histogram of S-component; (e) Histogram of V-component.

Table 3. Statistical features of color similarity of antiquing original red sandstone.

		Average Value	Range of Values	Standard Deviation	Qualified Rates
Group 1	1-1	0.667	(0.371,0.980)	0.180	50%
	1-2	0.671	(0.479,0.798)	0.087	60%
	1-3	0.796	(0.508,0.942)	0.120	90%
Group 2	2-1	0.457	(0.268,0.698)	0.119	15%
	2-2	0.586	(0.348,0.823)	0.123	20%
	2-3	0.700	(0.348,0.796)	0.132	80%
Group 3	3-1	0.532	(0.305,0.781)	0.138	20%
	3-2	0.568	(0.315,0.750)	0.118	35%
	3-3	0.764	(0.420,0.980)	0.193	60%

As can be seen from Table 3, the average value reflects the trend of the concentration of color similarity in each group, with values closer to 1 being more similar. In the antiquing group, groups 1-3 and 3-3s average values are larger, indicating that the color antiquing effect is the closest to the original red sandstone. The range of values reflects the range of extreme values of color similarity of the groups. The larger the range, the greater is the difference in color antiquing effect. Group 1-2 has the smallest value range, indicating the effect of antiquing in the group is uniform with no obvious color differences. The standard deviation reflects the degree of dispersion of the groups' similarity relative to the mean. The more homogeneous the antiquing effect, the smaller is the standard deviation, and vice versa. Group 1-2 have the least dispersion, indicating that the group is the most evenly antiqued with minimal color variation. As a limit of similarity, $S_{col} > S_{0col}$ indicates that the group's color antiquing effect is qualified. The groups 1-3 and 2-3 have the highest qualified rates. These two groups of color antiquing are most similar to the original red sandstone.

According to the color similarity analysis, we can see that the color antiquing effect of groups 1-3, 2-3, and 3-3 is superior, but the standard deviation of group 1-3 is smaller than that of groups 2-3 and 3-3, indicating that the color of group 1-3 is more uniform. Group 1-2 has the lowest standard deviation and the most consistent color, but its overall color similarity is not high.

4.2. Texture Antiquing Analysis

Tamura texture features are used in this paper to analyze the texture antiquing effect of red sandstone. Tamura texture features encompass a method for describing image texture that is based on psychological research into human visual perception of texture. It consists of six metrics: roughness, contrast, orientation, line image, regularity, and coarseness. In practical applications, only the first three features are generally used because they are linearly uncorrelated, whereas the last three features are linearly correlated with the previous three features [30,31].

Tamura texture features are designed based on the human visual system's perception of texture to capture effectively texture information in images, which makes it more in accord with human visual cognition when describing materials with complex textures such as red sandstone. As red sandstone is a rough rock with a specific directional texture, the directional feature can help to identify and describe the directional distribution of its texture; the roughness feature can help to quantitatively describe the roughness level of its surface; the contrast feature can help to analyze the textural variations and differences in different colors and brightness.

The calculation process of these three features is as follows:

$$F_{crs} = \frac{1}{m \times n} \sum_{i=1}^m \sum_{j=1}^n S_{best}(i, j) \quad (6)$$

$$F_{con} = \frac{\sigma}{\alpha_4^{1/4}} \quad (7)$$

$$F_{dir} = 1 - r \times n_p \times \sum_p^{n_p} \sum_{\varphi \in w_p} (\varphi - \varphi_p)^2 \times H_D(\varphi) \quad (8)$$

where F_{crs} , F_{con} , and F_{dir} respectively represent roughness, contrast, and orientation, S_{best} represents the optimal size of the set window, σ represents the standard deviation of the pixel grayscale value, α_4 represents the kurtosis of the grayscale values, n_p is the number of peaks in the histogram H_D , φ_p is the p th peak, w_p is the range between the valleys containing the p th peaks and r is the normalization coefficient associated with the quantization of φ .

The image is first pre-processed by median filtering, which is used to remove isolated noise points, reduce nonlinear noise, and effectively protect edge information. Then we compute the image texture features. Part of the image processing is shown in Figure 14.

The texture similarity calculation process used in this section is similar to that of color similarity in the previous section. The same procedure is used to extract three texture features of the two images: roughness, contrast, and orientation. Then we calculate the cosine similarity corresponding to the three features and use the minimum normalization principle to calculate the similarity corresponding to each component. Finally, we compute the average of the three similarity components to determine the overall texture similarity of the two images.

Similarly, according to Equation (2), we can calculate the texture self-similarity $S_{0tex} = 0.866$ of the original red sandstone, and also be able to obtain the texture similarity statistical features of each group of antiquing red sandstone, see Table 4.

From Table 4, we can see that the average value of group 1-3 is the largest, indicating that the texture antiquing effect is most similar to the original red sandstone. Except for group 1-2, the value range and the standard deviation of the remaining groups is not much

different, indicating that the texture of antiquing is basically uniformly distributed. The qualified rate of group 1-3 is the highest, and the group 3-2 is the second.

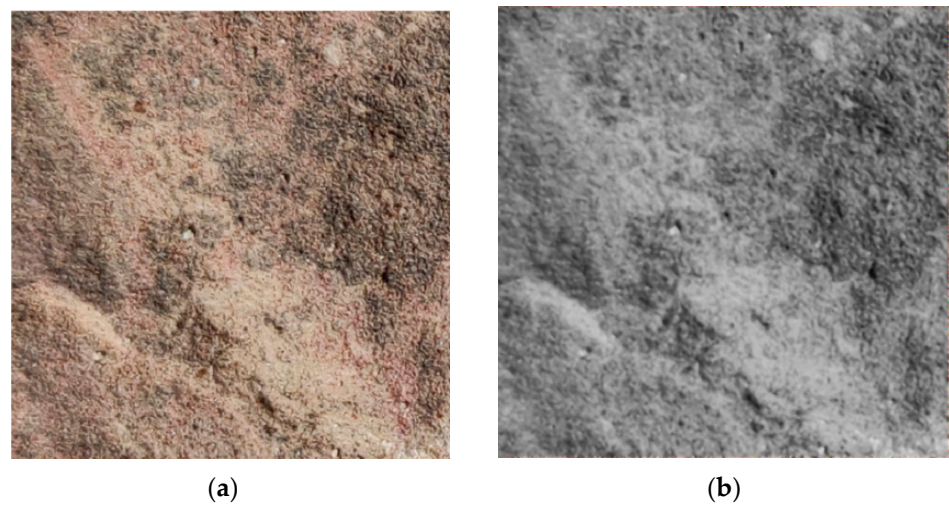


Figure 14. Diagram of filtering process of red sandstone image: (a) Original image; (b) result after median filtering.

Table 4. Statistical features of texture similarity of antiquing original red sandstone.

		Average Value	Range of Values	Standard Deviation	Qualified Rates
Group 1	1-1	0.819	(0.832,0.616)	0.082	30%
	1-2	0.835	(0.910,0.579)	0.106	35%
	1-3	0.914	(0.932,0.709)	0.073	65%
Group 2	2-1	0.795	(0.846,0.558)	0.098	20%
	2-2	0.852	(0.739,0.981)	0.076	45%
	2-3	0.843	(0.859,0.635)	0.080	40%
Group 3	3-1	0.823	(0.703,0.979)	0.081	30%
	3-2	0.865	(0.891,0.651)	0.078	50%
	3-3	0.850	(0.880,0.625)	0.087	45%

The texture similarity analysis reveals that groups 1-3 and 3-2 have the best texture antiquing effects.

4.3. Comprehensive Analysis

Through the above calculations, we obtain the color similarity and texture similarity of the image. We then use the CRITIC method to weigh the image color similarity and texture similarity to obtain the final comprehensive similarity. See Equation (1).

Based on consultation of the literature [32,33], three professors in the field of civil engineering and architecture in scientific research institutes and three engineers in cultural tourism project were consulted, and a total of six experts were scored to obtain six judgment matrices. The corresponding elements of each judgment matrix were summed up and averaged to obtain the average judgment matrix and scientifically calculated; the weight values of color similarity and texture similarity are obtained after consistency test and normalization. The average judgment matrix is shown in Table 5.

Table 5. Average judgment matrix.

	Color Similarity	Texture Similarity
Color Similarity	1	5/3
Texture Similarity	5/3	1

The calculated weights of color similarity and texture similarity are 0.625 and 0.375. Substituting the weights with the similarity calculated in the previous section into Equation (1) yields $S_0 = 0.726$.

Similarly, the final similarity between each antiquing group of red sandstone images and the original red sandstone images can be obtained. We can calculate the statistical features for analysis. The results of the overall similarity statistical features of the antiquing and original red sandstone are shown in Table 6.

Table 6. Statistical features of overall similarity of antiquing original red sandstone.

		Average Value	Range of Values	Standard Deviation	Qualified Rates
Group 1	1-1	0.724	(0.541,0.910)	0.102	40%
	1-2	0.733	(0.573,0.818)	0.075	50%
	1-3	0.840	(0.670,0.902)	0.063	90%
Group 2	2-1	0.584	(0.488,0.741)	0.078	10%
	2-2	0.686	(0.555,0.811)	0.073	25%
	2-3	0.754	(0.571,0.830)	0.073	70%
Group 3	3-1	0.641	(0.525,0.775)	0.082	20%
	3-2	0.680	(0.540,0.798)	0.075	30%
	3-3	0.797	(0.588,0.921)	0.109	60%

As can be seen from Table 5, group 1-3 has the largest average value of similarity, the smallest standard deviation, and the highest qualified rate. All the indexes are significantly better than other groups. The method is regarded as having the best antiquing effect.

The comparison graph of antiquing and original red sandstone is shown in Figure 15.

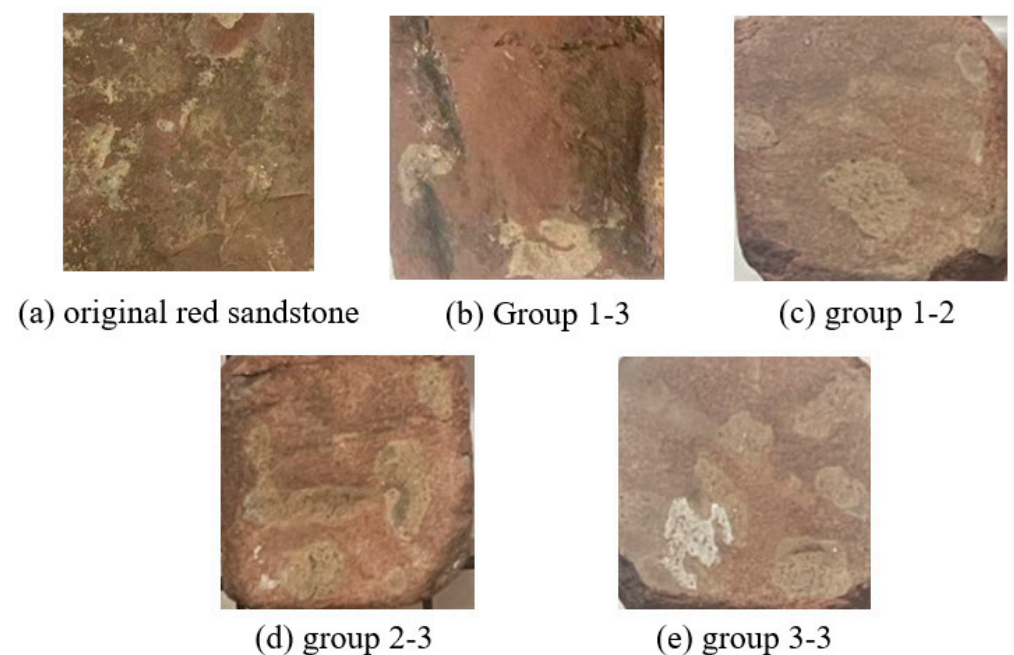


Figure 15. (a) Original red sandstone; (b) antiquing red sandstone of group 1-3; (c) antiquing red sandstone of group 1-2; (d) antiquing red sandstone of group 2-3; (e) antiquing red sandstone of group 3-3.

In terms of control variables, when using the same antiquing materials, the effect of antiquing in groups 1-3, 2-3, and 3-3 is significantly better than other antiquing effects in the same group. It shows that the effect of carbon black is relatively good at a concentration of 5 mL/L. However, the difference between the effects of the concentration of 1 mL/L and 2 mL/L is not obvious. For the same carbon black concentration, group 1, which contains both red clay and grass ash in the antiquing materials, has a better overall antiquing effect

than groups 2 and 3. It suggests that using red clay and grass ash in the materials is a viable option.

5. Conclusions

Based on the image processing method of HSV color space and Tamura texture features, we carried out experiments and effect assessment research of red sandstone rapid antiquing in restored buildings with the background of an ancient town building in Ganzhou, Jiangxi Province, and obtained the following conclusions:

(1) The red sandstone used in the restoration of ancient buildings was antiqued from image texture and image color, respectively, and the effect of antiquing was quantitatively analyzed by establishing an evaluation model and adopting the image processing method. The result shows that by adopting the experimental method and implementing the process of rapid antiquing of the new red sandstone, the process can satisfy the requirements of restoration of ancient buildings and improve the efficiency of red sandstone antiquing, that is feasible and practical.

(2) By analyzing the effect of red sandstone samples after antiquing with different process parameters, it was found that the antiquing image similarity of red sandstone in group 1-3 was significantly better than that of other antiquing groups in terms of mean value, standard deviation, and qualification rate, with the best effect. In the case of the other parameters being the same, the antiquing effect of red sandstone samples using 5 mL/L of carbon black liquid was better than other concentrations. In addition, the antiquing effect can also be enhanced by mixing red mud with plant ash. The results can provide a theoretical basis for red sandstone rapid antiquing in ancient architecture.

(3) This paper provides a set of rapid antiquing evaluation ideas for red sandstone in ancient buildings outlined as follows: first, select the old materials through pre-treatment, then determine the material ratio and antiquing process plan, and finally use the evaluation model to evaluate the effect in terms of both color and texture to select the optimal solution. Specific parameters can be adjusted as needed, while the operation process and method have feasibility and a certain universality, which can provide reference ideas for the restoration of other stone cultural relics.

(4) This paper only proposes the red sandstone rapid antiquing in the restoration stage of ancient buildings. However, attention should also be paid to the prevention and control of the deterioration of red sandstone in the complex environment after antiquing, which is also the guarantee of long-term service after the restoration of ancient buildings.

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