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Enhancing the Harmonious Aesthetics of Architectural Façades: A VETAR Approach in Mengzhong Fort Village's Stone Masonry

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Abstract: To enhance the continuity of character in the preservation of architectural heritage, this approach focuses on the horizontal self-similarity characteristics of architectural texture. A method using K-means and the Bhattacharyya approach for color selection in architectural repairs is proposed. It quantifies the visual coherence between the repaired structure and the original structure. Analyzing 12 images (A–L), with the original façade (image 0) as a reference, demonstrates that repairs using color-matched materials significantly improve visual coherence. Image A, created using the Visual Enhancement Through Adaptive Repair (VETAR) method, achieves the highest visual alignment with the original image. VETAR, grounded in Gestalt psychology, moves away from traditional materials to concentrate on visual consistency. Its successful implementation in the restoration of Mengzhong Fort illustrates a complex approach to material use in heritage conservation. After comparison, this method is deemed superior to traditional techniques, integrating modern interventions with historical aesthetics. The study suggests that VETAR may offer a referential method for architectural conservation, potentially facilitating a balanced integration of historical and contemporary elements in architectural renovation.

Keywords: architectural conservation; image processing; visual coherence; sustainable development; psychological principles

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1. Introduction

The integration of modern and historic architectural elements is a significant trend in contemporary architecture. Architects are now able to move away from static forms and historical construction methods, and instead, incorporate dynamic forms that integrate structure, building envelope, and form in designs [1]. This integration allows for the coexistence of unique modern buildings with historical ones, by using the right policies and methods [2]. The aim is to create architectural buildings that harmonize and integrate with their surrounding historical buildings, preserving the cultural heritage and values of the site [3]. By adapting and developing heritage elements, architects can produce architectural products that link authenticity and contemporary design, maintaining cultural continuity and creating a unique identity [4]. The goal is to create architectural environments that combine traditional elements and symbols with modern forms and ideas, resulting in a cultural fusion that reflects both the historical and modern atmosphere [5].

Building textures exhibit self-similarity [6], and for visual continuity, we can apply the guiding principles of Gestalt. The adoption of Gestalt principles in design significantly enhances the coherence of visual elements, guiding the design process to more effectively capture selective human attention. These principles, when applied, have been instrumental in achieving superior results in graphic design work, underscoring their importance in creating visually appealing and coherent compositions [7]. Gestalt psychology has been applied in the field of architectural restoration to promote beauty, identity, and memory as essential dimensions for collective and individual well-being [8]. By emphasizing a cultural inclination and considering the human dimension, design-oriented processes can create hospitable and welcoming physical and relational spaces [9]. This approach recognizes the importance of the experiential use of spaces and the value of the memory layered in complex historical spaces [10]. Psychological studies also suggest that changing the outside world can be therapeutic, indicating that psychology merges with ecology in the context of architectural restoration [11]. By integrating design, psychology, and restoration, opportunities arise to develop the potential of the built environment, promote multiple functions and reuse methods, and create spaces that contribute to collective and individual well-being [12].

The architectural landscape of villages is a key component influenced by the surrounding environment, culture, and social dynamics. Zhou & Zheng [13] proposed an integrated approach to traditional villages in river basins, considering historic relics, locality, and spatial form, and introduced the concept of cultural routes to link geographically scattered villages to stimulate their potential for rural revitalization.

In the realm of architectural conservation, the guiding principle is to ensure that modern interventions do not compromise the building's historical integrity [14]. This is particularly complex given that architectural character is not just a physical attribute but also a subjectively complex visual experience [15]. The concept of 'Gestalt', rooted in psychology, is central here. A Gestalt is an experiential construct where each component is interconnected, and the attributes of individual components are influenced by their relationship dynamics [16]. This concept has significant implications for traditional village architecture renovations [17]. Since the assessment of a village's appearance is often subjective, rooted in individual visual experiences, the pixelated design of digital camouflage offers a compelling parallel [18]. Gestalt psychology, as used by Cesare Brandi, is pivotal in the conservation and restoration of art, particularly in addressing and interpreting losses [19].

By integrating human visual perception models into the design process, we can bridge the gap between traditional craftsmanship and modern technological innovations [20]. This ensures that renovated structures meet modern functional requirements while also resonating with those who experience them, satisfying both aesthetic and psychological needs.

This research, grounded in the principles of Gestalt psychology, has developed the Adaptive Restoration Enhancement Visual Augmentation Technique (VETAR). This innovative approach modernizes traditional architecture while preserving its historical integrity, utilizing both image processing and psychological principles. The technique employs the K-means algorithm to extract colors from the architecture, ensuring that new additions to the building visually align with the original structure. Moreover, the Bhattacharyya distance is applied to gauge the visual similarity between the new and old parts of the building, maintaining architectural features during renovation. The core of VETAR is its interdisciplinary approach, blending modern technological applications with traditional aesthetics. This respects architectural heritage and satisfies modern functional needs, offering significant benefits for the preservation of architectural heritage and reducing landscape disruption in building restoration.

2. Materials and Methods

2.1. Geographic Location of Mengzhong Fort

Mengzhong Fort, located in Mengzhong Village, Xieluo Tibetan Township, Sichuan Province, China, stands over 1700 m above sea level, covering an area of approximately 6000 m^2 (Figure 1). The village, 27 km from Shimian County and 8 km from the township government, is strategically positioned in the "Ethnic Corridor", a vital route to Yunnan and Tibet. It comprises 56 households and 215 Muya Tibetan ethnic group members, organized into three community groups. The local economy is primarily based on agriculture, animal husbandry, and seasonal labor. Despite considerations for relocation, the community has expressed a preference for enhancing their traditional dwellings with modern technologies.

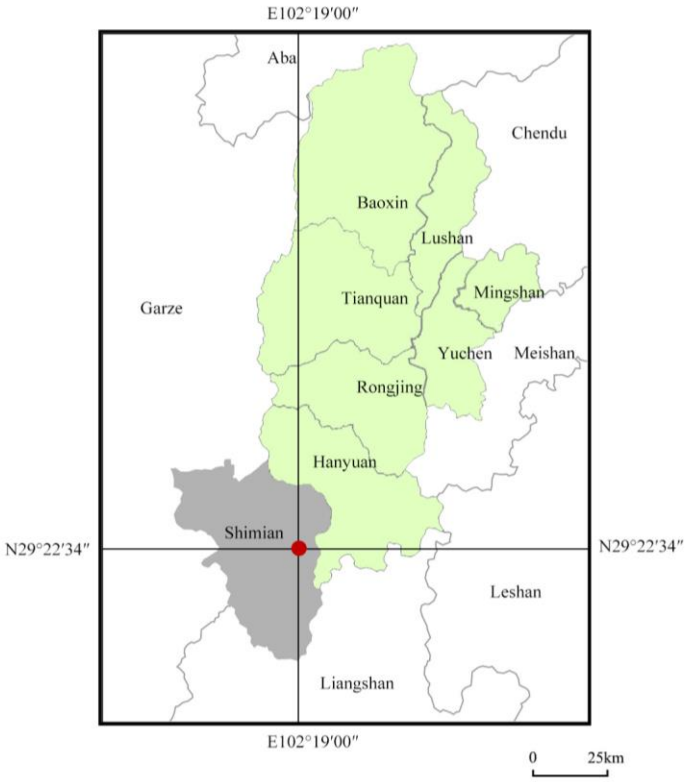

Figure 1. Geographical location of Mengzhong Fort.

As a provincial-level cultural heritage site, Mengzhong Fort is distinguished by its Muya Tibetan architecture and cultural practices, including the "Sun Buddha Festival", underscoring the importance of its preservation.

The region's mid-latitude subtropical monsoon climate, moderated by the Dadu River Valley, presents an ideal setting for the stone architecture of Mengzhong Fort. With an average annual temperature of 17.1 °C and most of the yearly rainfall of 1663.7 mm falling between May and September, the climate contributes to the stability and habitability of the stone structures (Figure 2). The elevation significantly influences temperature and precipitation, further aligning with the fort's construction, which provides resilience against the elements and a comfortable habitat for its inhabitants [21].

Figure 2. The overall style of Mengzhong Fort.

2.2. Balancing Modernization and Tradition: A Case Study on Architectural Updates in Mengzhong Fort Village

Field research indicates that the demand for indoor comfort is rising with improved living standards, particularly in traditional villages like Mengzhong Fort in Sichuan. This has led to self-initiated renovations that sometimes compromise the traditional appearance of these residences, especially following natural disasters like the earthquakes in 2008 and 2014 [22].

While societal expectations do press for the preservation of cultural traditions [23], the renovation approach needs to be balanced. It should focus on creating an acceptable indoor atmosphere as illustrated in Figure 3. The changes should also adapt to local climatic conditions, and proactive measures should be taken to maintain elements of traditional architecture. Modern technologies can be introduced for challenges like decay and waterproofing, aiming to preserve both the traditional appearance and ecological footprint [24,25].

Figure 3. Transitional style.

The renovation should aim to improve comfort levels with low energy consumption, acting as filters rather than barriers to traditional appearance [26]. This aligns with the global trend of adaptively reusing historic buildings for environmental and cultural sustainability.

2.3. Mengzhong Fort Building Classification

2.3.1. Innovative Approaches for Blending Modern and Traditional Elements in Architectural Conservation: Insights from Village Practices

To preserve and enhance architectural landscapes, we use a two-pronged approach. A classification system [27] categorizes buildings based on appearance, significance, materials, and operational status. Additionally, a widely-used system [28] differentiates façades into Modern and Traditional Material Exteriors, informing conservation strategies and ensuring restorations respect the building's original aesthetic and historical context, as shown in Table 1.

Table 1. Classification of Buildings and Enclosures.

Traditional Village Building Categories	Enclosure Structure Categories
Traditional Residential and Community Buildings	Modern Material Enclosure
Mixed and Transitional Buildings	Traditional Material Enclosure

1. Traditional Residential and Community Buildings

Figure 4 shows Traditional Residential and Community Buildings as a tangible link between past and present, with Figure 5 highlighting the blend of traditional architecture and modern aspects, reflecting a living cultural story. Integrating modern features in traditional buildings serves to both enhance functionality and preserve cultural identity. Façade continuity, as a renewal approach, allows architectural heritage to evolve while respecting its origins, crucial for maintaining a community's visual and cultural coherence and safeguarding it for future generations.

Figure 4. Traditional residential and community buildings.

Figure 5. Traditional residential buildings.

2. Mixed and Transitional Buildings

Mixed and Transitional Buildings, illustrated in Figure 6, reflect a community's architectural evolution. Conservation prioritizes maintaining their unique features while modernizing them for energy efficiency and ensuring compliance with preservation guidelines. These buildings enrich the community's visual and architectural diversity, serving as connectors between historical and contemporary styles, and are key to preserving the area's unique identity.

Figure 6. Mixed and transitional buildings.

3. Maintenance structure

To facilitate the cultivation of crops and the rearing of domestic livestock, some villagers opt to use wire fencing to partition land, as shown in Figure 7b. However, this practice visually conflicts with the historical appearance and street landscape of traditional villages. Therefore, the primary strategy during the updating process is to focus on partial renovations and material replacement. Specifically, materials that clash with the historical appearance and street landscape but still have utility value will be replaced with local stone, as depicted in Figure 7a, or other new materials that can seamlessly integrate into the traditional village aesthetic.

(**a**) (**b**)

Figure 7. (**a**) Traditional residential buildings; (**b**) modern materials (wire fencing) to maintain the building.

2.3.2. Optimizing the Use of Modern Materials in Traditional Architecture: Design Strategies for Village Restorations

The villagers' utilization of modern materials in the renovation of traditional buildings offers a poignant insight. The use of contemporary materials undeniably brings a level of convenience that cannot be overlooked. However, due to technical limitations, the villagers primarily focus on the ease of repair, inadvertently overlooking the preservation of the traditional architectural aesthetic. In our restoration efforts, it is imperative to place greater emphasis on the continuity of architectural style, ensuring that the restoration process respects and maintains the intrinsic character of the traditional structures. At this juncture, the application of Gestalt principles becomes essential, providing a holistic perspective that balances modern utility with the preservation of historical authenticity.

2.4. Harnessing Gestalt Psychology for Harmonious Architectural Renewals in Traditional Village Landscapes

Gestalt concepts play a pivotal role in architecture by providing insight into human visual perception and organization, which are essential for architectural design. Principles like proximity and similarity guide architects in structuring and interpreting stimuli based on relationships and commonalities, resulting in more cohesive and efficient designs. Integrating Gestalt principles into the curriculum of architectural education fosters creative thinking and problem-solving skills in students, equipping them to tackle design challenges effectively and practically. This approach in architectural education sharpens students' abilities in perception, abstraction, and communication, as well as teamwork. In essence, leveraging Gestalt creativity in architecture deepens the understanding of how individuals perceive and engage with architectural spaces, culminating in designs that are both more effective and centered around human experience [29].

In the realm of architectural conservation, ensuring that modern interventions harmonize with the historical integrity of buildings is a complex endeavor. This complexity is heightened by the subjective nature of architectural character, which encompasses not only physical attributes but also the visual experiences of observers. To navigate this, our study adopts a cross-disciplinary approach, informed by the Gestalt principles of perception as shown in Figure 8. These principles, which posit that humans perceive visual elements as part of a greater whole, are particularly pertinent when considering the harmony of materials with the surrounding landscape. The Gestalt-Perception Transformer model, as discussed by Hu et al. [30], exemplifies the application of these principles, where the visual features of diagrams—akin to the façades of buildings—are grouped into perceptual wholes, enhancing the observer's holistic experience.

Figure 8. Color block camouflage vs. digital camouflage.

Further refining our approach, we draw upon existing models of human visual perception to establish a strategic framework for aesthetic continuity in architectural renovations. This framework aids in the selection and arrangement of new materials, ensuring alignment with the natural perception mechanisms of the human eye. The impact of Gestalt theory on the development of interior architecture designs, as explored by Ahmed [31], underscores the relevance of perceptual processes in design, which can be translated into the language of architectural renovation to foster a dialogue between the user and the design elements.

By integrating these insights into our methodology, we ensure that the renovated structures not only meet modern functional requirements but also resonate on an aesthetic and psychological level with those who experience them.

2.5. Employing Computer Vision and Image Processing for Aesthetic Harmony in Architectural Renovation

The modular approach to renovation draws inspiration from the construction techniques used in Mengzhong Fort, where the exteriors are crafted using a combination of stone and mud mortar. Each of these elements—stone and mud—serves as an irregular yet crucial module that contributes significantly to the overall architectural aesthetic. Additionally, villagers' ingenious utilization of damaged spaces has provided valuable insights for the design process, particularly in the context of material selection, as illustrated in Figure 9. This concept is further bolstered by the inherent modularity of Lego bricks and the efficiency of mass-produced prefabricated components. The objective of such a strategy is to conserve the rich historical and aesthetic fabric of traditional villages.

Figure 9. Residents' use of dilapidated spaces.

To address the "block effect" that is often a byproduct of modular construction, principles from Gestalt psychology are invoked. The aim here is to morph visually intrusive, large color blocks into a series of smaller, cohesive shapes. This not only diminishes the visual impact of the renovation but also ensures that the refurbished areas harmonize seamlessly with their existing surroundings. To accurately replicate the native color palette of the villages, we suggest employing computer vision and image processing techniques. These techniques can automatically extract primary colors from the existing environment or images. One such technique involves the application of the K-means clustering algorithm to distill a few representative colors from complex visual data. These colors not only hold visual significance but often dominate the overall tone of the scene. This approach thus ensures a level of visual harmony that is both psychically appealing and culturally respectful, enhancing the acceptance of the renovations.

Bhattacharyya distance, by contrast, provides a more nuanced measure, as it considers the overall distribution of pixel values, allowing for a more robust and effective comparison in complex image scenarios. The K-means clustering algorithm has been widely used for color quantization and feature extraction in computer vision and image processing. Various clustering techniques, such as fuzzy c-means, mean-shift, and HKmeans, have been applied to identify the color of digital images [32]. Additionally, a novel partitional color quantization algorithm based on a binary splitting formulation of MacQueen's online k-means algorithm has been proposed, which addresses both the initialization and acceleration issues of k-means [33]. Another approach utilizes L1 principal component analysis (PCA)-informed K-means to preserve the color definition of images [34]. Furthermore, a novel color quantization method based on an online k-means formulation has been developed, which utilizes adaptive and efficient cluster center initialization and quasi-random sampling to achieve high speed and high-quality quantization [35]. These methods demonstrate the effectiveness and efficiency of utilizing the K-means clustering algorithm for color quantization and feature extraction in computer vision and image processing.

The Bhattacharyya distance has also been utilized in statistical similarity matching for image categorization, where it has shown effectiveness compared to the Euclidean distance [36]. Furthermore, the KNN + Bhattacharya distance method has been used in image inpainting, providing effective performance in terms of evaluation metrics and higher efficiency compared to traditional approaches [37].To mitigate the "block effect" commonly associated with modular construction, we integrate principles from Gestalt psychology. This strategy transforms large, visually intrusive color blocks into smaller, cohesive shapes, reducing the visual impact of renovations and ensuring seamless integration with the existing environment. To replicate the native color palette of villages, computer vision and image processing techniques are employed. Techniques like the K-means clustering algorithm distill representative colors from complex visual data, capturing the scene's dominant tones. This approach fosters visual harmony, appealing to both aesthetic and cultural sensibilities, and enhancing the acceptance of renovations. The relation of Bhattacharyya distance to Gestalt psychology lies in their shared focus on visual information processing and interpretation. In computer vision, the Bhattacharyya distance quantifies the similarity between probability distributions of image features, while Gestalt principles explain the human perception of these features as a unified whole, rather than isolated parts. This synergy could be pivotal in understanding and simulating human perception in computational applications.

Considering the analysis presented, we advocate for a paradigm shift in renovating traditional village structures. Existing methods have often compromised the visual harmony intrinsic to these historic landscapes. The dissonance arises chiefly from the use of incongruous renovation materials and a disregard for the native color palette. We propose a solution that employs modularization in wall construction, combined with principles of Gestalt psychology in the design of material appearances. For instance, replacing commonly used materials like ordinary cement mortar with colored concrete can offer both durability and aesthetic flexibility.

In our research, the image transformation process was carried out using Spyder (Python 3.1.1) in the Anaconda environment. We employed a method based on image histograms to evaluate and compare the similarity between images. This method involves image processing using the OpenCV library, along with the matplotlib library for plotting and analyzing image histograms.

Initially, one image is selected as a reference, and then it is compared with a series of other images. Since the color is restricted within a limited range, each image is first converted into a grayscale format to facilitate the calculation of its grayscale histogram. These histograms are then normalized to ensure the consistency of statistical data.

The similarity between images is determined by calculating the Bhattacharyya distance between the grayscale histograms of two images. The Bhattacharyya distance is a measure of the similarity between two statistical sample distributions and is well-suited for analyzing the degree of similarity in image content.

To present the results more intuitively, we plotted histograms for each pair of images and saved them as image files for further analysis and presentation. This process not only provided us with quantified similarity scores but also enabled us to visually understand the similarity between images through the comparison of histograms. The technical route is shown in Figure 10.

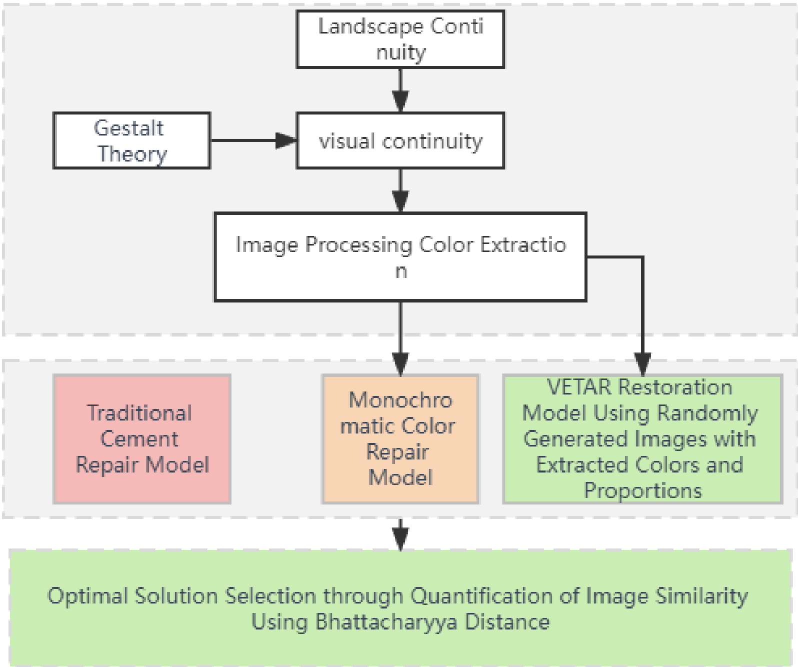

Figure 10. Technological route.

2.6. Mathematical Definition and Application of Bhattacharyya Distance

2.6.1. Color Extraction and the K-Means Algorithm

First, the primary colors in the background are extracted using the K-means algorithm. The mathematical formulas behind the K-means algorithm mainly involve two steps:

Assignment Step: Each data point (in this case, pixels in the image) is assigned to the nearest cluster center. The distance is usually calculated using the Euclidean distance. Here, Si is the ith cluster, xp is the data point, and μi and μj are the cluster centers. The Euclidean norm is denoted by $\|.\|$:

$$Si = \{xp :|| \; xp - \mu i \; || \; 2 \leq || \; xp - \mu j \; || \; 2 for \; all 1 \leq j \leq k\} \tag{1}$$

Update Step: The centers of the clusters are recalculated, usually by taking the mean of all points in the cluster. Here, $|Si|$ is the number of data points in cluster Si, and xj is a data point in Si:

$$\mu_i = \frac{1}{|S_i|} \sum_{x_j \in S_i} x_j \tag{2}$$

Value of K (n_clusters): This is the number of "clusters" (i.e., primary colors) to be found in the K-means algorithm. Here, it is set to 10. That is, the algorithm will divide all pixels in the image into 10 clusters, each represented by a primary color.

Kmeans = KMeans(n_clusters = 10)

Data Points (pixels): The line pixels = img.reshape(−1, 3) in the code transforms the image into an $N \times 3$ matrix, where N is the number of pixels in the image, and 3 corresponds to BGR(Blue, Green, Red).

In computational practice, it is observed that the K-means clustering algorithm, when applied to a singular image across multiple iterations, may yield marginally varying outcomes due to its stochastic nature. However, these variations are typically negligible, allowing the initial computational results to be retained with a high degree of confidence. This consistency underscores the algorithm's robustness for image analysis applications where reproducibility is paramount.

Cluster Centers (colors): The line colors = kmeans. cluster centers_ retrieves the centers of each cluster, which are the BGR values of each primary color. Based on the above algorithm, ,we are given the BGR values for ten different colors and their corresponding percentages from Figure 11, as shown in Figure 12.

Figure 11. Image 0—The Original State of the Wall.

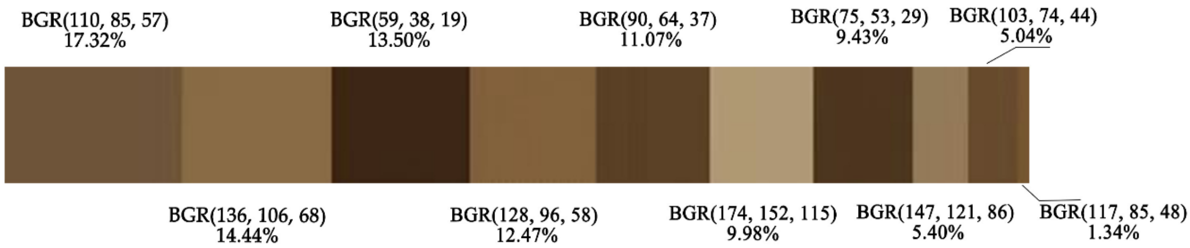

Figure 12. Color BGR and its scale.

2.6.2. Quantifying Image Similarity through Bhattacharyya Distance in Histogram Analysis

In image processing and computer vision, quantifying the similarity between two images is a fundamental task with applications ranging from image retrieval to medical imaging. Traditional metrics like Euclidean distance or Manhattan distance often fall short when dealing with high-dimensional spaces or various types of noise in images. Bhattacharyya distance, a measure based on probability distributions, offers a robust and nuanced metric for image similarity. This paper employs Bhattacharyya distance as a means to evaluate the likeness between histograms of different images.

The Bhattacharyya distance is a metric used for measuring the similarity between two probability distributions. In this context, the two probability distributions are the histograms of two grayscale images. The mathematical definition of the Bhattacharyya distance, denoted as DB (P, Q), is −ln(sum(i) sqrt ($pi \times qi$)), where P = {p1, p2, . . ., pn} and

Q = {q1, q2, . . ., qn} are the two probability distributions, and n is the number of bins in the distributions.

Step 1: Compute the Square Root of the Product for Each Dimension (or Bin). In this step, the corresponding elements *pi* and *qi* from P and Q, respectively, are multiplied and then the square root is calculated: sqrt ($pi \times qi$). This operation is done for all *i* values.

Step 2: Summation of the Square Root Products. Next, sum up all of the square root products computed in Step 1: sum(*i*) sqrt ($pi \times qi$).

Step 3: Take the Negative Natural Logarithm. Finally, take the natural logarithm (ln) of this sum and then negate it: $-\ln(\text{sum}(i)\ \text{sqrt}\ (pi \times qi))$. This gives the Bhattacharyya distance, DB (P, Q).

Physical or Statistical Interpretation. The Bhattacharyya distance measures the extent of overlap between the two distributions. When both distributions are identical (P = Q), the Bhattacharyya distance is zero. When there is no overlap, it tends towards infinity. The distance has the following properties:

- When DB = 0, P and Q are identical distributions.
- The larger the value of DB, the less similar P and Q are.

To make the ratio more intuitive, it is often termed as the "Bhattacharyya Coefficient" or "Bhattacharyya Distance" in the field of image processing. For a more intuitive description, the term "Image Similarity Score" is chosen, scaled between 0 and 1 or 0 and 100. The conversion formula is: Similarity Score = $(1 - \text{DB}) \times 100$.

Thus, a higher "Similarity Index" or "Similarity Score" would intuitively indicate that the two images are more alike. In histograms, a "bin" is a term for a data range used for classifying a set of data points. Specifically, in the context of image processing, a histogram describes the distribution of pixel values in an image. A grayscale image histogram usually has 256 bins, corresponding to 256 different levels of gray (ranging from 0 to 255).

Each bin contains the number of pixels within a certain range of gray values. For instance, in a 256-bin grayscale image histogram, the first bin might represent the number of pixels with a gray value of 0, the second bin might represent the number of pixels with a gray value of 1, and so on, up to the last bin which represents the number of pixels with a gray value of 255. In the histogram, the *x*-axis represents the bins (in this case, the levels of gray), and the *y*-axis represents either the number of pixels in each bin or the probability density of that pixel value when normalized.

$$normalizedvalue = maxvalue - minvalueoriginalvalue - minvalue \times (beta - alpha) + alpha$$

In this formula, "originalvalue" refers to the original value of a specific bin in the histogram, while "minvalue" and "maxvalue" represent the minimum and maximum values within the histogram. "alpha" and "beta" define the target range, meaning that the normalized values will fall within this range.

Through such normalization, the values in the histogram are adjusted to a common scale, typically ranging from 0 to 1 (when setting alpha = 0 and beta = 1). This makes it easier and more accurate to compare the histograms of two different images.

2.6.3. Preserving and Modernizing Traditional Architecture through Adaptive Repair and Multi-Disciplinary Collaboration

In the realm of vernacular architecture, which is finely attuned to local climates and resources, modernization poses a risk to the integrity of traditional, climate-responsive designs [38]. As we transition into an age of increased technological intervention, computational methods from fields like image processing and computer vision offer innovative ways to preserve these architectural legacies. Specifically, the use of Bhattacharyya distance as a similarity metric can assist in evaluating the impact of modern modifications on traditional forms, providing a nuanced understanding that goes beyond traditional metrics like Euclidean or Manhattan distances [39,40]

Just as Figure 9 underscores the need to harmonize with, rather than dominate, the natural environment, these computational techniques can serve as "filters," aiding architects in making updates that respect the original design while enhancing comfort and sustainability [41,42].

This approach mandates a multi-disciplinary perspective where architects, often outsiders in traditional settings, collaborate with computer scientists and local craftsmen. This synergy could redefine how we perceive the value of traditional designs, emphasizing their innate intelligence and adaptability [43].

2.6.4. Generation and Application of Visual Repair Material

The traditional "restoring the old as old" approach faces challenges, particularly when replacing stones in masonry walls. This method is labor-intensive and can disrupt visual harmony, resulting in a "patchwork" appearance, as depicted in Figure 13.

Figure 13. Traditional cement mortar repair model.

After extracting the primary colors and their respective proportions from the surrounding environment, the next step is to generate a random image that incorporates these elements, as shown in Figure 14. This generated image serves as a visual repair material for the walls. It aims to seamlessly coordinate with either the surrounding environment or specific design elements, taking into account both the color and proportion of each extracted hue. This strategy takes into account both repair needs and aesthetic continuity. During renovation, efforts are made to visually integrate the work with the existing environment. While addressing the repair issues, it also preserves the architectural character, enhancing the visual harmony of the space. This approach aligns with Gestalt principles, emphasizing the overall unity and balance in the perception of the environment.

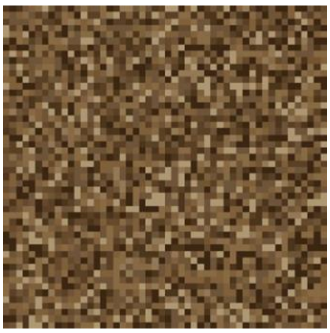

Figure 14. Optimized visualization of random shapes colored according to primary proportions.

Therefore, renovation methods should meet practical needs while preserving the village's traditional architectural character. Technological advancements should also be integrated to meet residents' modernization aspirations [44]. We name this repair method 'Visual Enhancement Through Adaptive Repair' (VETAR) as depicted in Figure 15.

(**a**) (**b**)

Figure 15. (**a**) VETAR method; (**b**) common ordinary cement mortar repair methods.

Quick fixes often involve the use of cement or other modern materials as fillers. The VETAR fix is similar to Figure 15a. While expedient, these methods can compromise the traditional architectural style, as shown in Figure 15b. They may enhance the building's longevity but often fail to maintain its traditional appearance [45].

3. Results

3.1. Utilizing Image Processing and Psychological Principles for the Continuation of Architectural Character

3.1.1. Image Similarity and Bhattacharyya Distance

In the comparative analysis between images A–L and image 0, image A employs color-coordinated repair material, while image B acts as a control using traditional concrete repair methods. Images C through L demonstrate individual trials with various colors for repair, as depicted in Figure 16, following a single color block pattern from Figure 12. Metrics including histogram comparisons and Bhattacharyya Distance calculations assess visual similarity for each pair. These metrics are integrated into a final Similarity Score, providing a quantifiable measure of the visual coherence each technique achieves. This systematic approach allows a comprehensive evaluation of various wall repair methods, underscoring the significance of aesthetic considerations in urban environmental restoration projects.

Comparing each of the above repair methods with VETAR, the following comparative histogram was obtained (Figure 17). The Similarity Score is presented in Table 2.

Table 2. Bhattacharyya Distance and Similarity Score.

Image Label	Bhattacharyya Distance	Similarity Score
A	0.0414	95.86
B	0.2127	78.73
C	0.1665	83.35
D	0.1693	83.07
E	0.1807	81.93
F	0.1718	82.82
G	0.1823	81.77
H	0.1934	80.66
I	0.1847	81.53
J	0.1881	81.19
K	0.1889	81.11
L	0.1899	81.01

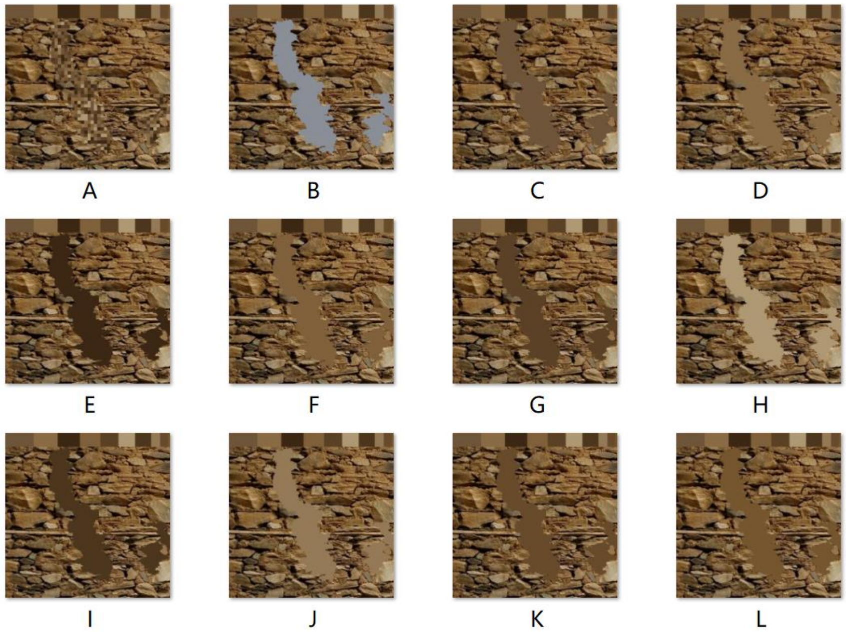

Figure 16. Different cements for repairing walls. (**A**) Color-coordinated repair material; (**B**) control using traditional concrete repair methods; (**C**–**L**) individual trials with various colors for repair.

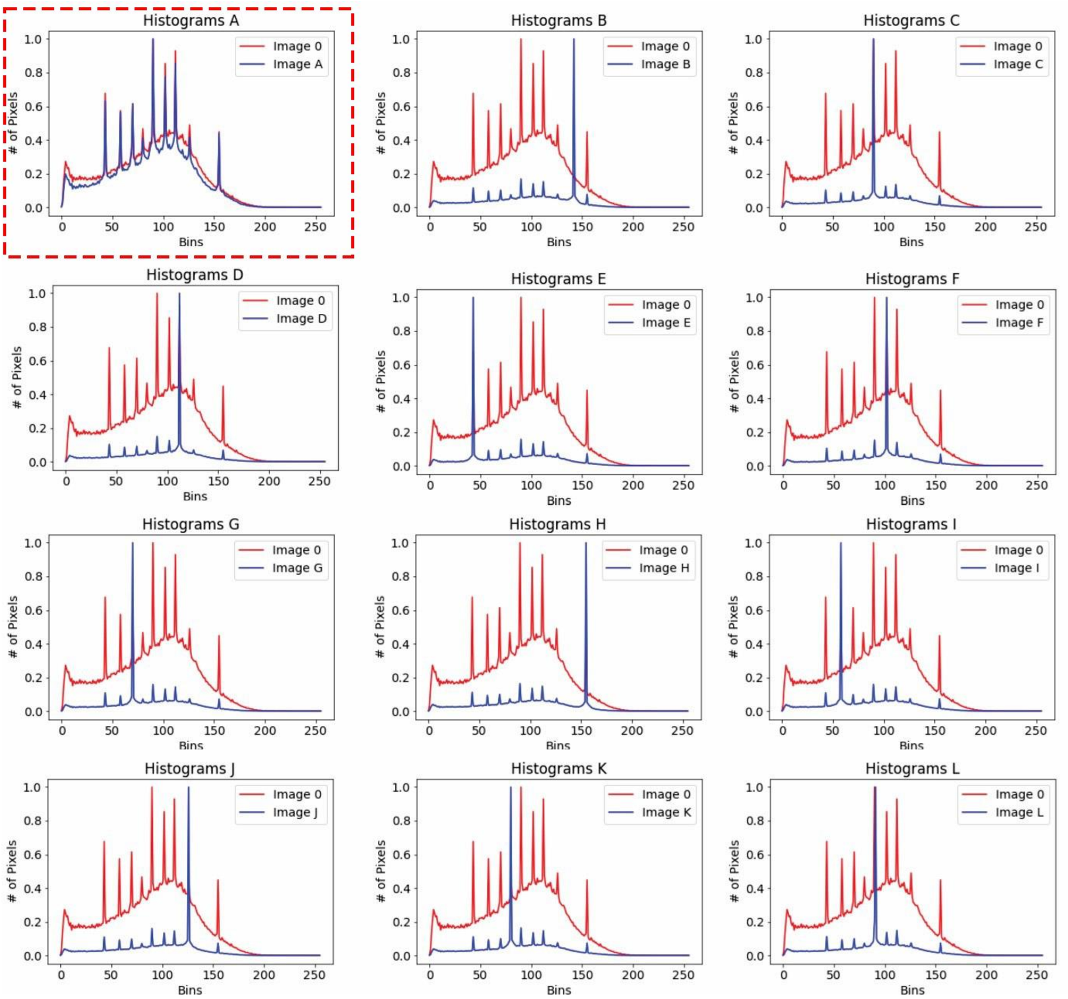

Figure 17. Comparison of histograms of different repair methods. Image A (see Figure 16) is outlined in red dashed lines; other letters correspond to Figure 16.

The horizontal axis (X-axis) represents "Bins". In image processing, a "bin" denotes a range of pixel intensities in a histogram. For grayscale images, these bins typically represent different levels of gray. In this code, as 256 is used for the number of bins, the histogram has 256 bins corresponding to gray levels from 0 to 255.

The vertical axis (Y-axis) represents "number of pixels", which is the number of pixels in each bin. This value indicates how many pixels fall within that specific range of gray level in the image.

In this code, the cv2.calcHist function is used to calculate the histogram of the image. The output of this function is an array, where each element's value represents the pixel count for the corresponding bin. These values are then used to draw the histogram, where the height of each bin corresponds to the number of pixels at that level of gray.

In the generated histogram, the histograms of two images are overlaid for comparison:

The red curve represents the histogram of "image 0".

The blue curve represents the histogram of another image being compared, such as "A", "B", etc.

After comparing the histograms of images B through L with the reference image 0, there are clear differences in the arrangement of peaks and troughs. These variations indicate differing degrees of visual coherence with the reference image, which can be attributed to the various repair techniques and materials utilized in each case. While image A (outlined in red dashed lines) demonstrates high consistency with the reference histogram, the other images differ, showing variations in their grayscale value distributions. These differences are apparent in the spacing and height of the histogram bars, suggesting that the color matching or texture consistency may not be as precise as that achieved with the VETAR method used for Image A.

The remaining histograms exhibit additional peaks or different peak structures, which may indicate that the repair materials used have different textural properties compared to the original structure.

3.1.2. Similarity Scoring and Data Analysis

Based on the Similarity Scores provided for images A–L in comparison to image 0, it is evident that the scores vary significantly, ranging from 78.73 to 95.86, as displayed in Table 2. Here is an analysis of the data:

1. Histograms A stands out with the highest Similarity Score of 95.86, indicating that it Image A is the most visually coherent with image 0. This suggests that the repair material and technique used in image A are the most effective in preserving the visual integrity of the environment when compared to the standard represented by image 0.
2. On the other end of the spectrum, image B has the lowest score at 78.73, pointing to the least visual resemblance to image 0. This implies that traditional concrete repair methods are less effective in maintaining visual coherence, based on the criteria set for this analysis.
3. The scores for images C through L are tightly packed within the range of 80.66 to 83.35. Although none of these images achieve the high similarity of image A, they do represent a moderate level of visual coherence with image 0. This suggests that varying the colors used in repair does have an impact but not as significant as the technique or material used in image A.
4. It is worth noting that the scores for images C–L are relatively close to each other, indicating that while there may be slight differences in visual coherence due to the different colors used for repair, these differences are not particularly pronounced.

3.1.3. Wall Repair and Structural Module Design

After analyzing the dimensions of the wall's stone and mortar, it was determined that the basic structural module should be designed as a rectangular block with cross-sections ranging from 2–5 cm, as depicted in Figure 18. This figure showcases a variety of shapes for prefabricated components. From left to right, the figure illustrates the wall surfaces that require repair(Assume that the area within the blue block needs to be repaired.). For holes, prefabricated pieces of the same thickness as the wall should be used. For wall repairs, the VETAR method should be applied.

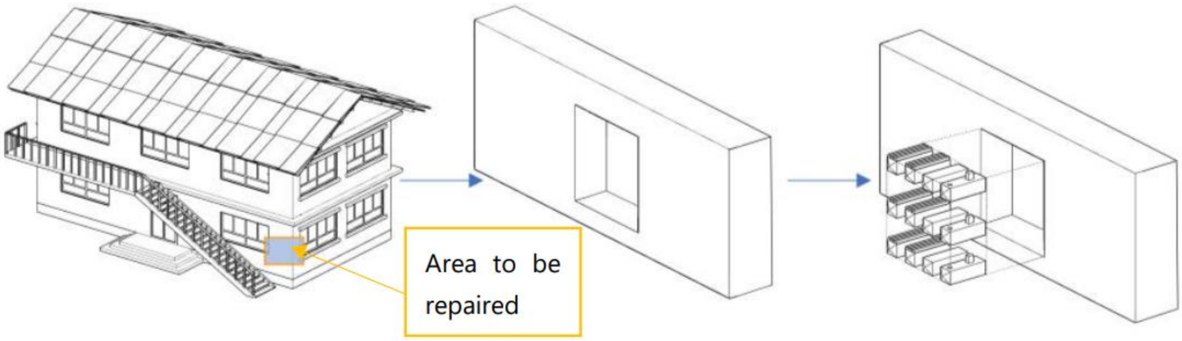

Figure 18. Application of the VETAR method for structural wall repair.

This size also allows for the sanding down of the original materials at the interface between the unit and the wall, thereby improving the overall integrity of the updated retaining structure. The assembly method resembles Lego blocks and can be resized according to the wall surface that needs to be updated. To restore the appearance of walls that have already been damaged, thin slices can be directly placed over walls that have been updated with cement, which would mitigate the damage to the traditional village's aesthetic caused by previous repair methods. Depending on the size of the area to be updated, multiple cross-sections can be combined and directly manufactured to guide the production of traditional materials in various forms [46].

3.2. VETAR in Practice: Balancing Heritage and Modernity in Architectural Renovation

By applying VETAR, architects gain a tool that not only honors the heritage and aesthetics of traditional settings but also provides a practical avenue for modern updates and repairs. This groundbreaking approach has the potential to redefine architectural conservation strategies, striking a fine balance between preservation and modernization.

Utilizing translucent concrete prefabricated components informed by Gestalt psychology significantly mitigates the visual disruption commonly associated with traditional repair methods. This approach allows for the rapid design of repair solutions, facilitating the renovation and replacement of damaged areas in buildings like Mengzhong Fort.

Comparative images clearly demonstrate that material updates guided by Gestalt psychology are more effective in preserving the traditional aesthetics of villages than straightforward cement mortar repairs. Given that buildings in Mengzhong Fort generally have small window areas, the added transparency helps improve interior lighting while maintaining the original architectural features as shown in Figure 19.

VETAR's capability to mimic natural environments surpasses traditional methods of artificial texturing and aging, minimizing the visual impact of the new materials. These materials, while new, also become part of the historical fabric, blending into the aesthetic landscape and extending the architectural narrative.

Traditional village architecture often relies on natural ventilation via thermal and wind pressures, generally facilitated through unsealed holes at the junctions of doors, windows, and building components. VETAR can incorporate passive ventilation features that meet modern living standards. During the update process, active ventilation systems can also be integrated into the wall components.

In addition to constructing new memorials using recycled materials, VETAR can also address the limitations in the availability of old materials while infusing a sense of modernity into restored buildings as seen in Figure 20, where the repaired section is outlined with red dashed lines.

Figure 19. Schematic representation of the updated landscape.

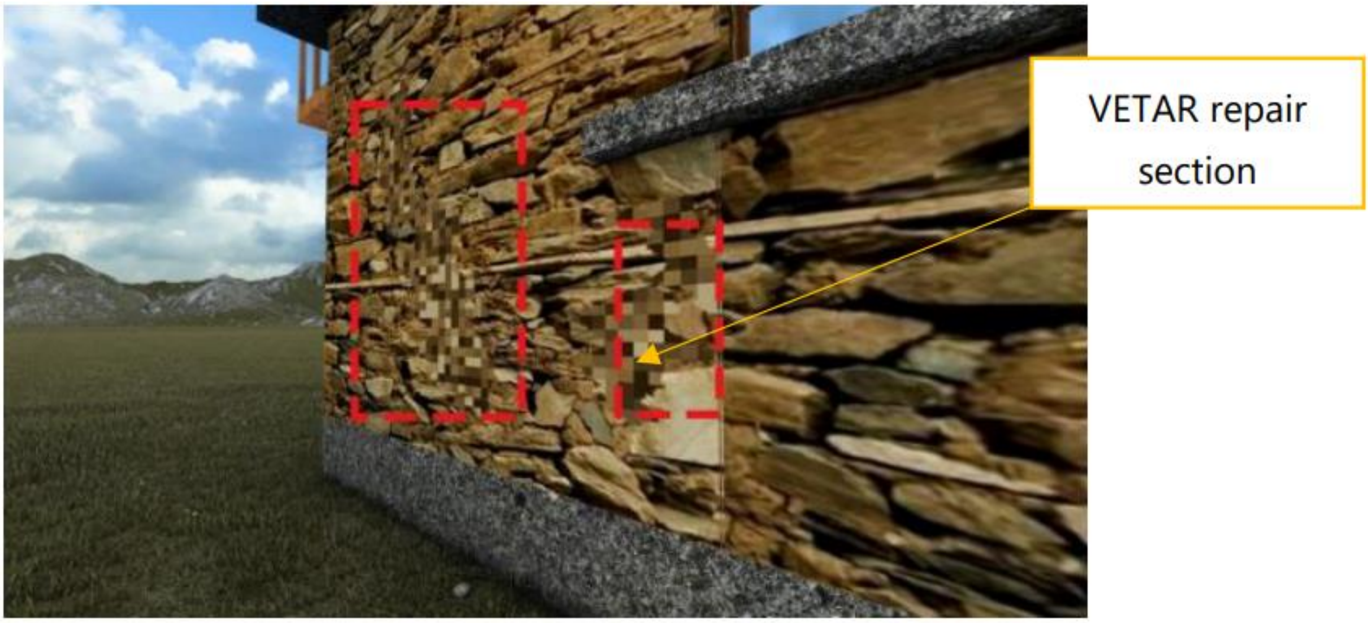

Figure 20. Enhanced integration of contemporary design elements in architectural continuity.

Interior walls also require special attention. In cases where the walls are severely damaged, transparent concrete can be employed as a viable solution. This innovative material not only offers structural integrity but also has the added benefit of enhancing indoor natural lighting. This approach aligns well with the principles of VETAR, which aim to balance modern updates with traditional aesthetics while considering practical needs.

Architects have amassed extensive experience in material handling through diverse construction practices. Local materials, when thoughtfully processed, yield unique results. Whether utilizing new materials and technologies or repurposing existing ones, architects have achieved numerous successes in rural construction that aptly reflect local characteristics.

The essence of this study is to present a novel approach, Visual Enhancement Through Adaptive Repair (VETAR), which synergizes image processing and psychological principles to sensitively modernize traditional architecture. The core technique involves the K-means algorithm to extract colors from an environment, ensuring that any new additions to a building are visually congruent with the original structure. Moreover, the Bhattacharyya distance is utilized to measure the visual similarity between old and new, preserving the architectural character during renovations. The key findings indicate that VETAR effectively merges modern technological applications with traditional aesthetics, facilitated by a collaborative, interdisciplinary methodology. This approach not only respects the historical integrity of heritage buildings but also meets the functional demands of contemporary use.

The study's conclusions advocate for a balanced integration of technology in architectural restoration, aiming to be comprehensible to a broad scientific audience and highlighting the importance of maintaining cultural continuity in our built environment.

Gestalt psychology, in the context of image processing, emphasizes the human perception of images as whole entities rather than just the sum of their parts. This perspective is vital in understanding how images are interpreted and processed visually.

The Bhattacharyya Distance, on the other hand, is a statistical measure used for quantifying the similarity between two probability distributions, often used in image processing to compare the histograms of images.

The conceptual link here is that while Gestalt psychology provides a framework for understanding visual perception, the Bhattacharyya Distance offers a mathematical tool for quantitatively analyzing this perception in terms of image similarity.

Advantages Over Traditional Quantitative Methods: Traditional quantitative methods like Euclidean or Manhattan distances are straightforward but can be limited in handling the complexities of high-dimensional data and different types of image noise.

4. Conclusions

Traditional cement mortar restoration methods have been known to disrupt the architectural character of historical buildings. This finding has catalyzed the exploration of alternative approaches that not only repair but also preserve and enhance the original aesthetic qualities of historical structures. As an extension to conventional practices, this research has investigated the innovative intersection of image processing techniques and psychological principles to uphold and continue the architectural character in renovation projects.

By implementing the K-means algorithm for color extraction within the VETAR system, we have established a method that ensures new repair elements are visually harmonious with existing materials. This approach, which integrates primary colors and their proportions, masks imperfections while maintaining aesthetic continuity. This blend of techniques offers a sophisticated alternative to standard quantitative methods, preserving architectural character and enhancing both structural and aesthetic continuity. Our study strikes a balance between preserving historical integrity and meeting modern needs, contributing significantly to sustainable cultural heritage preservation.

We analyzed the similarity scores of images A–L using the Bhattacharyya distance, in comparison to image 0 as detailed in Table 2, which indicates a notable range from 78.73 to 95.86. Image A (generated using the VETAR method) emerges as the most visually coherent with image 0, scoring the highest similarity at 95.86. This suggests that the repair materials and techniques used in image A are exceptionally effective in preserving the environment's visual integrity. In stark contrast, image B, with the lowest score of 78.73, exhibits the least visual resemblance to image 0. This implies a lower efficacy of traditional concrete repair methods in maintaining visual coherence. The scores for images C to L, while moderately coherent with image 0, show a close clustering within a narrow range. This observation suggests that while variations in repair colors have an impact, they do not significantly alter visual coherence as much as the methods employed in image A.

While the research provides promising strategies for maintaining the aesthetic integrity of traditional villages through the VETAR method, its limitations are acknowledged, particularly the need for further practical testing and refinement. Future research should focus on evaluating long-term sustainability and incorporating interdisciplinary approaches to better understand community needs and responses. Additionally, the study's focus on Mengzhong Fort suggests limited generalizability. The unique environment and conditions of Mengzhong Fort indicate that our findings may not apply universally to all heritage conservation scenarios. Each heritage site has distinct historical, cultural, and physical characteristics, influencing conservation effectiveness. Thus, caution is advised when applying these findings to other locations, and future research should consider the diversity of heritage sites, exploring a broader range of conservation strategies to ensure widespread applicability and effectiveness.

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