Research Article

Digital Image Analysis and Pattern Recognition of the Artistic Expression and Evolution of Lotus Patterns in Goguryeo Murals in Ji'an

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ARTICLE INFO	ABSTRACT
	Ancient Chinese murals have a splendid history in ancient times, experiencing thousands of years and countless dynasties. There have been artistic classics such as Dunhuang murals that are still applauded, and the murals of Goguryeo in Ji'an are also impressive. Through systematically combing and analyzing the lotus pattern in the Goguryeo murals in Ji'an, this paper reveals the artistic expression, style changes, and cultural factors behind the lotus pattern in different historical periods. It is found that the lotus pattern in the Goguryeo period not only showed an evolution trend from simplicity to complexity and from realism to abstraction in form but also reflected the profound transformation from nature worship to Buddhist belief to royal power symbolism in meaning. However, due to the age of the murals and the interference of natural climate and artificial damage, most of the murals have been damaged, falling off, cracks, and other pathological problems, which need to be protected urgently. Therefore, the combination of mural restoration and computer technology, the use of digital technology, vision and pattern recognition technology, the restoration of mural images for automated pattern recognition and analysis of mural paintings to assist in virtual restoration, not only for artificial restoration to provide an important and practical significance of the value of the reference, but also after the restoration of the mural paintings for the digitization of long-term preservation.

Keywords: Goguryeo Murals in Ji'an, Lotus Pattern, Artistic Expression, Evolutionary Analysis.

INTRODUCTION

In ancient times, Goguryeo, an essential country in Northeast China, has always been a hot spot in academic research for its unique cultural and artistic heritage (Guo et al., 2024). Among them, as one of the political, economic, and cultural centres of Goguryeo, the Ji'an area has preserved a large number of precious tomb murals, which not only vividly record the daily life, religious beliefs, and aesthetic tastes of the Goguryeo people (Lee & Chung, 2023), but also are essential material materials for the study of Goguryeo and ancient cultural exchanges in East Asia. Among the many mural themes, the lotus pattern has attracted the attention of many scholars with its unique artistic charm and far-reaching cultural connotation (Fang et al., 2024 & X. Sun, 2023).

The lotus flower has a crucial symbolic meaning in Goguryeo culture; it symbolises cleanlin (Gu et al., 2022). In the Goguryeo murals in Ji'an, lotus patterns appear in various forms, from simple pattern decorations to complex scene depictions, showing Goguryeo artists' in-depth exploration and artistic expression of the lotus theme (Gomoiu et al., 2022). With time, these lotus patterns have undergone significant changes in form and connotation, reflecting the evolution of Goguryeo society and culture, foreign culture's influence, and local culture's innovation. Although there have been extensive studies on Goguryeo murals, systematic research still needs to be done on the artistic expression and evolution of lotus patterns in the Ji'an area. At the same time, many murals have been damaged because of age, and the relevant personnel used modern science and technology

to combine traditional techniques to reproduce the complete murals (Furtado & Payne, 2023).

Therefore, this paper attempts to explore the artistic expression, style evolution and cultural significance behind the lotus pattern in the Goguryeo murals in Ji'an through a detailed analysis and to deeply study the research status of image restoration at home and abroad. It aims to reveal the artistic characteristics and changes of the times of the Goguryeo lotus pattern and then profoundly understand the exchange and development of Goguryeo and even the ancient culture of East Asia.

LITERATURE REVIEW

Artistic Expression of the Lotus Pattern in the Murals of Goguryeo in Ji'an

Form and Style

As an essential birthplace of Goguryeo culture, the mural art of the Ji'an region not only shows the daily life, religious beliefs, and social systems of the Goguryeo people but also integrates rich natural and symbolic elements, among which the lotus pattern is one of its prominent representatives. Among the 20 Goguryeo mural tombs in Ji'anji, 16 have painted lotus patterns. In some tombs, the main body of the mural is decorated with a painted lotus pattern. These lotus patterns reflect the worship of Buddhism by the Goguryeo people and play a solid decorative role in the real life of the Goguryeo people (Chen et al., 2021). The painters of Goguryeo captured the lotus form in real life through concise brushstrokes, outlined into an image pattern, skilful, simple, and vivid, with the unique artistic style of the Goguryeo nation, it is a precious material for studying the history of the ancient Goguryeo nation in China (Li, 2022).

The lotus pattern in the Goguryeo murals in Ji'an has a variety of forms, ranging from simple lines to complex and detailed depictions (Macchia et al., 2021). Most of these patterns are open or semi-open, and the lotus petals are layered, either lightly rolled or elegantly unfolded, reflecting the Goguryeo artists' profound observation of natural beauty and superb artistic expression. The stems of the lotus flowers are usually erect or slightly curved (Himmi & Elalamy, 2023). In contrast, the lotus leaves are presented in their characteristic floating form, sometimes in the same frame as the lotus flowers and sometimes in an independent scene, adding to the dynamic beauty and layering of the picture (Jie & Chaetnalao, 2023).

In terms of composition, the lotus pattern often does not exist in isolation. Still, together with other elements such as water birds, clouds, fish, and insects, it forms a harmonious and vibrant scene (Fang et al., 2023). This composition not only shows the beauty of the lotus flower itself but also conveys the Goguryeo people's philosophy of harmonious coexistence and nature worship through the interaction of the lotus flower with other elements. This artistic expression of the lotus pattern is undoubtedly deeply rooted in the cultural soil of Goguryeo, reflecting its unique aesthetic orientation and cultural connotation.

From the perspective of artistic style, the Goguryeo murals in Ji'an show a characteristic that is both classical and vivid. Its lines are smooth and elastic, and the colours are primarily natural and pastel, which not only retains the natural texture of the lotus but also gives it a richer emotional and symbolic meaning. In addition, with time, the lotus pattern also showed an inevitable trend of evolution in form and composition, which reflected the development of technology and aesthetic concepts and the artistic integration and innovation under the influence of foreign culture, as shown in Figure 1.

Figure 1. The Main Composition of the Goguryeo Murals in Ji'An

Colors and Techniques

The lotus pattern in the Goguryeo murals in Ji'an is diverse and expressive. The artists carefully selected colours to achieve a harmonious, vivid visual effect. The primary colours include soft natural tones such as light green, light blue, pink, and white, which faithfully reflect the natural colour of the lotus and give the picture a fresh and refined beauty. It is worth noting that the use of colour often considers the effect of light and shadow. The three-dimensional sense and dynamic beauty of the lotus pattern are enhanced through contrast and gradient techniques (Liang et al., 2022).

In terms of technique, the Goguryeo murals in Ji'an show the superb skills of Goguryeo artists. They use line outlining, colour filling, chiaroscuro, and other techniques to express the details and texture of the lotus flower delicately (Lin et al., 2022 ; Moretti et al., 2024). Among them, line sketching is the basis for the lotus pattern, and the artists use smooth and powerful lines to show the outline and structure of the lotus according to the different growth states of the lotus (Riegl, 2020; Zou & Yeo, 2024). The colour filling further enriches the layers and emotions of the picture, and the artists make the lotus pattern both natural and artistic through the clever combination of colour shades, cold and warm. In addition, the use of chiaroscuro, especially in expressing the layers of lotus petals and the texture of lotus leaves, shows the delicate grasp of light and shadow effects in Goguryeo murals (Mezzadri, 2021; Himmi & Elalamy, 2023).

With time, the colour and technique of the lotus pattern in the Goguryeo murals in Ji'an also showed an inevitable evolution trend. From the early simple lines and single colours, it gradually developed into complex compositions and rich colours in the later period. This change not only reflects the development of Goguryeo's social culture and the influence of foreign culture but also reflects the innovation and progress of artists in technology and aesthetic concepts (X. Sun, 2023).

Cultural Symbolism and Connotation

The lotus flower symbolizes purity, beauty, rejuvenation, and eternity in many cultures (Vettraino et al., 2023). The widespread use of lotus patterns in the Goguryeo murals in Ji'an reflects the Goguryeo society's admiration for these values. The lotus flower can grow in the mud without staining, symbolizing noble character and the spirit of defying difficulties. At the same time, the life cycle of the lotus flower, from seed to bloom to fruit, symbolizes the cycle and rebirth of life, reflecting the Goguryeo people's deep understanding of life and the laws of nature (Lee & Han, 2023)..

The appearance of the lotus pattern in the murals of the Goguryeo in Ji'an is also closely related to the religious beliefs of the time. After Buddhism was introduced to Goguryeo around the 4th century AD, it profoundly impacted Goguryeo's culture and art (Xu et al., 2024). As an important Buddhist symbol, the lotus flower represents purity, holiness, and enlightenment. In murals, lotus flowers are often used to decorate Buddha statues, symbolizing the purity of the Dharma and the light of wisdom. This religiously coloured lotus pattern not only shows the belief and respect of the Goguryeo people for Buddhism but also reflects the integration of Buddhist culture and local culture.

The artistic expression of the lotus pattern in the Goguryeo murals in Ji'an is also related to the philosophical ideas and social values of the Goguryeo people. Growing the lotus flower, struggling out of the soil and finally blooming is seen as a symbol of perseverance and self-purification. This aligns with the Taoist philosophy of conforming to nature and being quiet in the heart. At the same time, this characteristic of the lotus flower was also used by Goguryeo society to symbolize the virtue of a gentleman, that is, to maintain personal purity and nobility in a complex social environment (Rivaroli et al., 2021).

Evolution Process and Influencing Factors of Goguryeo Murals

Evolution of Time Series

By observing and comparing lotus patterns in murals in different periods, we can understand more deeply the cultural changes in Goguryeo society and the influence of foreign cultures. In the early stage of Goguryeo murals, the lotus pattern was simple, mainly outlined by lines, and the colour was straightforward. The lotus patterns of this period were primarily used to represent religious scenes or as decorative elements, and their expressions were relatively direct, reflecting the intuitive feelings and expressions of natural beauty by Goguryeo artists. Although simple, the lotus motifs in these early works already reflect the importance of the lotus flower in Goguryeo culture (Tang et al., 2020). With time, especially in the gradual penetration of Buddhist culture into Goguryeo society, the representation of lotus patterns in Goguryeo murals in Ji'an became more complex and rich. The lotus patterns of this period were not only more diverse in form, such as the appearance of more open or semi-open lotus forms, but also more refined in colour and technique. Artists began experimenting with different colour combinations and shading to enhance the three-dimensionality and vividness of the lotus pattern. These changes reflected the maturity of Goguryeo's mural art and the acceptance of Buddhist art aesthetics in Goguryeo society. In the late Goguryeo period, with the increasing exchanges with China and other surrounding cultures, the lotus patterns in the Goguryeo murals in the Ji'an area showed more apparent characteristics of artistic integration. The lotus patterns of this period not only continued to maintain the characteristics of diverse forms and rich colours but became more complex and delicate in composition and expression. Artists pay more attention to the harmonious symbiosis between the lotus flower and the surrounding environment, and the lotus pattern is often combined with water birds, clouds, and other elements to form a poetic artistic conception. In addition, the influence of foreign cultures has also made the symbolic meaning of the lotus pattern more diverse, reflecting the inclusiveness and innovation of Goguryeo culture in openness.

Influence of Foreign Cultures

With the development of history, especially cultural exchanges with China, India and Central Asia, the lotus patterns in Goguryeo murals show obvious external cultural influences, reflected in the shape, colour, imagery and expression of the lotus patterns.

In the early days, Goguryeo's contact with Han culture, especially the introduction of Buddhism from China to Goguryeo, profoundly impacted the artistic expression of lotus patterns. In Chinese culture, the lotus flower symbolizes purity and elegance, and Buddhism regards the lotus flower as a symbol of holiness. After these cultural elements were introduced to Goguryeo through Buddhism, the lotus pattern began to carry richer religious and philosophical meanings. In the Goguryeo murals in Ji'an, it can be observed that the lotus pattern began to adopt more delicate lines and rich colours, as well as pay more attention to the combination of lotus flowers and Buddhist figures or scenes, reflecting the influence of Chinese culture, especially Buddhist culture, on Goguryeo mural art. Since Buddhism initially originated in India, the impact of Indian culture on the lotus motifs in Goguryeo murals cannot be ignored. The lotus flower in Indian culture symbolizes divinity, life's creativity, and the universe's order. These symbolic meanings spread to Goguryeo through Buddhism, and the lotus pattern began to carry deeper cosmic and religious-philosophical connotations. In some murals, the lotus flower is a decorative element and an important symbol to express the order of the universe and Buddhist philosophical ideas.

With the prosperity of the Silk Road, cultural exchanges between Goguryeo and Central Asia and further afield became increasingly frequent. This cross-cultural exchange allowed the lotus motifs in Goguryeo murals to absorb elements of the artistic styles of Central Asia and other regions. For example, the lotus motifs in some murals tend to be more abstract and decorative, which may have been influenced by regional art styles such as Persia. In addition, the introduction of foreign techniques and materials may also have contributed to the diversification of the lotus pattern.

Innovation in Local Culture

As an essential tribe in the ancient Northeast region, Goguryeo initially believed in primitive totem worship. In the Goguryeo murals of Ji'an, the lotus pattern may have been initially influenced by the local primitive totemic beliefs, incorporating the worship and expression of the vital forces of nature. As a plant that grows in water, the

lotus flower may be seen as a symbol of the continuation and prosperity of life, and this concept has influenced the way the lotus pattern is expressed and given meaning in the murals. Goguryeo is located in Northeast Asia, and its unique geographical environment and climatic conditions have also influenced the evolution of lotus patterns. In the Goguryeo murals of Ji'an, the lotus pattern may have undergone morphological changes to adapt to the local climate and natural environment characteristics. The lotus pattern may pay more attention to the growth state of the lotus flower in a humid environment or reflect the influence of local seasonal changes on the lotus, and these characteristics have become the local cultural factors in the evolution of the lotus pattern.

With the development and transformation of Goguryeo's social culture, the meaning of the lotus pattern gradually evolved. In the early days, the lotus flower may have been seen more as a totemic symbol or a natural element. Still, with the introduction of Buddhism and changes in the structure of society, the lotus flower began to carry more religious and philosophical significance. In the Goguryeo murals of Ji'an, the evolution of the lotus pattern reflects the transformation of Goguryeo's social and cultural concepts, and the lotus flower is not only a decorative element but also an important symbol to express the order of the universe and spiritual pursuit.

METHODOLOGY

THE RESTORATION PROCESS OF LOTUS PATTERN IN GOGURYEO MURAL IN JI'AN BASED ON COMPUTER ALGORITHM

Digital Scanning and Image Reconstruction

The mural images are converted into digitized high-resolution image data to scan the Goguryeo murals in Ji'an digitally. Then, the image processing algorithm was used to reconstruct and repair the scanned image, fill in the missing lotus pattern part and restore the damaged structure. This step involves reconstruction algorithms in image processing and texture-filling techniques, which allow the missing lotus pattern to be restored through analysis and processing of the image.

In the scanning and reconstruction of images, it is necessary to scan and analyze the abstract features of the image to recover the detailed information of the picture and obtain the diversified feature information of different scales by constructing a multi-scale decoder to effectively enhance the ability of mural image perception and reconstruction, as shown in Figure 2.
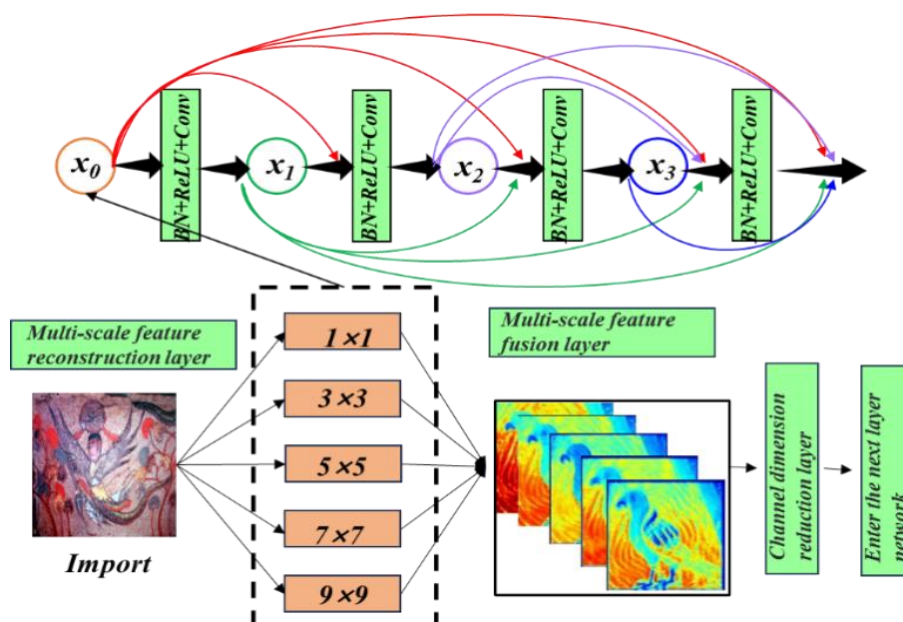

Figure 2. Schematic Diagram of a Multiscale Decoder

After the structure-guided encoding subnetwork completes the encoding, the encoded feature map is input into the decoding subnetwork. Design a texture-guided decoding sub-network consisting of a decoder, texture guide, and directional attention module. To consider the directionality of the texture information, the OAM direction attention module is designed to enhance the directional feature information of the texture feature map, and finally, under the prior information and guidance of the texture direction feature, the texture direction feature

and the decoded feature are fused layer by layer, so that the texture feature is transmitted between the layers. The correlation between the mural and texture features under different levels is used. To improve the ability of the decoder to generate texture detail information, the schematic diagram of texture-guided decoding is shown in Figure 3.

The subjective evaluation index of the image is used to intuitively evaluate the quality of the image according to the ability of the human eye to perceive it. Usually, a group of evaluators are selected to score the restored mural images, and the average of the scores of all evaluators is used as the subjective score of the restoration result, expressed as the MOS score. To ensure that all participants in the scoring followed a uniform scoring scale, the image inpainting effect was discretized into five grades, each corresponding to a different score, as shown in Table 1.

Table 1. Classification of Image Inpainting Effects

| MOS Score	Repair Effect	Quality Grade
5	No traces of repair can be found, and the overall effect is natural	Excellent
4	Traces of a smile are present, but do not affect the overall effect	Good
3	There are obvious traces, which affect the overall effect	So so
2	There are visible traces that affect the overall effect	Difference
1	There are serious marks, which greatly affect the overall effect	Very Poor
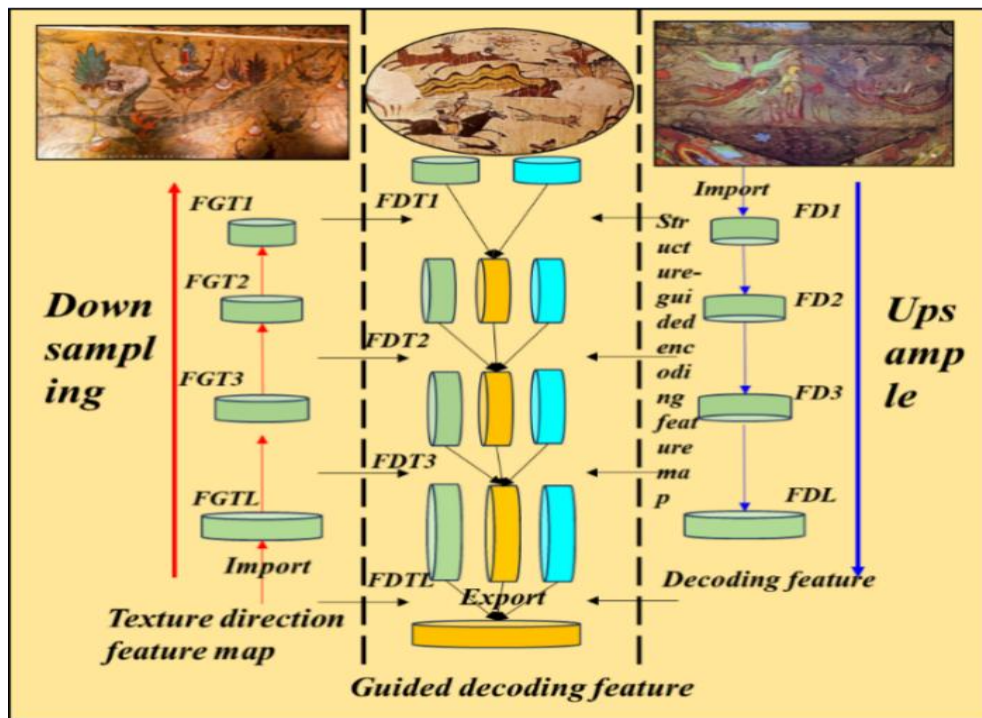
Figure 3. Schematic Diagram of Texture-Guided Decoding

To verify the effect of the algorithm on reconstructing ancient murals, several low-resolution murals were randomly selected from the reconstructed high-resolution murals with four times magnification, and the corresponding low-resolution murals for comparative observation, and the low-resolution images were observed. In addition, from the reconstruction of low-resolution images with fewer details, the image restoration is relatively complete, and the details are not inferior to other reconstructed murals. The PSNR (Peak Signal-to-Noise Ratio, a widely used image quality evaluation metric, is calculated based on the pixel values of an image) and SSIM (Structural Similarity, which is more in line with human visual characteristics compared to the PSNR.) The SSIM is designed to measure the degree of structural similarity of the two images, and has a value between -1 and 1, with a larger value indicating a greater similarity between the two images. The calculation of SSIM involves the comparison of three aspects: luminance, contrast and structure.) are shown in Table 2, and it can be seen from the table that the reconstructed murals also have good PSNR and SSIM values. From the above aspects, it is proved that the proposed algorithm has good stability.

Table 2. SSIM and PSNR After the Reconstruction of the Frescoes

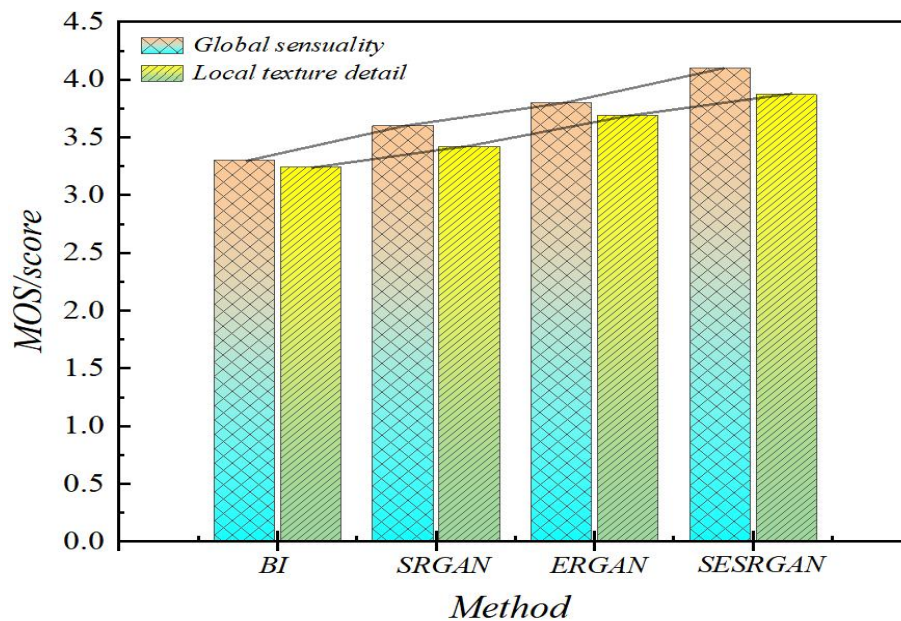| Image	a	b	c	d
PSNR	28.71	32.03	30.04	32.11
SSIM	0.876	0.782	0.851	0.768

Figure 4. Subjective Rating of the Mural After Reconstruction

The subjective ratings of 50 evaluators on the reconstruction of the ancient murals in different styles in Figure 4 are shown in Figure 4. After evaluation and discussion by the evaluators, it is unanimously concluded that the overall sensory performance of the proposed algorithm is more in line with human visual perception than other algorithms, and it also has better effects on brightness and image smoothness. In terms of local texture details, after comparing the generated murals with the existing murals, the evaluators believe that the reconstruction effect of the algorithm is ideal, and more accurate information is restored in the low-resolution images, which have a specific research value. By comparison, the overall perception and local detail texture scores are also better than those of other algorithms, so the proposed algorithm also has good convincing in subjective scoring.

Table 3. Comparison of IS With BN Layer and SN Layer

Period	a	b	c	d	e
Contains BN layer	7.31	6.47	7.06	5.36	5.45
Contains SN layer	9.54	8.25	7.03	6.49	7.24

It can be seen from Table 3 that the IS score of the discriminant network with BN layer is generally lower than that of the discriminant network with SN layer after training, indicating that the discriminant network with SN layer can help the whole network training to be stable, and make the murals generated by the generated network more precise and more realistic.

Automatic Pattern Recognition and Analysis

Computer vision and pattern recognition technology automatically identify and analyze the restored mural images. By training a deep learning model, the computer can automatically identify the lotus pattern in the mural and extract and examine its features. This step can help determine the lotus pattern's position, morphology and stylistic characteristics and provide an essential reference for subsequent restoration work.

The mural materials used for testing in this paper are the murals that research scholars focus on, including the Sui and Tang dynasties, the Ming and Qing dynasties, and other dynasties, endowed with multiple forms of themes, after consulting relevant research experts, the murals are roughly divided into eight categories: secular people, plants, bodhisattvas, animals, architecture, auspicious clouds, Buddha disciples and Buddhas for

classification experiments. In this experiment, each type of mural dataset was divided into two groups; one data group was used for training, and the other was used for testing. Due to the lack of datasets, the data augmentation method was used to augment the dataset, including scaling, luminance transformation, noise, flipping, etc., and 11630 datasets were used in the final experiment. The distribution of mural datasets is shown in Table 4.

Table 4. Experimental Dataset Allocation

Category	Training	Test	Total
Buddha	1360	340	1700
Bodhisattva	1200	300	1500
Buddha disciple	1280	320	1600
Secular	1344	336	1680
Auspicious clouds	1000	250	1250
Lotus pattern	1104	276	1380
Plant	1072	268	1340
Building	994	186	1180
Total	9354	2276	11630

You must set the appropriate learning rate and number of categories to ensure the training model has good generalisation ability. Set the parameter batch batch_size to 16 to speed up the network training. In addition, the probability of retaining the hidden element keep_pro is set to 0.5 to improve the model's generalisation ability by discarding some of the background features of the mural when extracting data information during the training process. As shown in Table 5.

Table 5. Parameter Settings

The Name of the Parameter	Options	Size Settings
Category	Labels_num	8
Batch	Batch_size	16
Learning rate	Base_lr	0.01
The number of iterations	Max_step	20000
Save Interval - Snapshot	Snapshot	2000
Preserve hidden cell probabilities	Keep_pro	0.5
The interval between the training logs is displayed	Train_log_step	100
Verify the log display interval	Val_log_step	100

In the image preprocessing module, the Gaussian kernel function is used to process the input image to generate an image pyramid: (1, 1/2, 1/4) scale image, and the colour reproduction subnet adopts the network structure based on Encoder-Decoder. The colour reproduction subnet in the first stage directly uses the image features generated by the image preprocessing module to restore the current image features and generate the restored image features through the colour reproduction network based on style attention. The colour reproduction network of the second and third stages uses the fusion features of the cross-scale feature fusion module of the stage as input, respectively, and the colour reproduction subnet is shown in Figure 5.
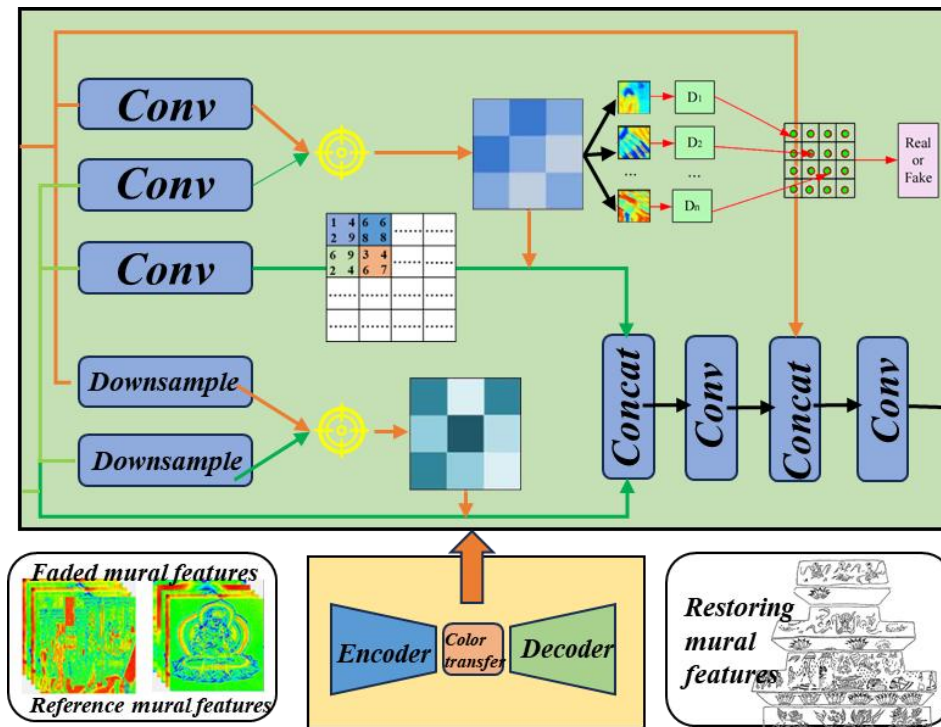
Figure 5. Color Reproduction Subnets

Table 6. Accuracy Comparison Table Under Different Algorithms

	GoogleNet	VGG	MCSN
fo	74.15%	76.63%	82.16%
pusa	81.98%	77.31%	85.45%
people	72.35%	79.64%	81.88%

It can be seen from Table 6 that when the histogram coincidence degree and dash value are the same, the classification accuracy of Buddhist disciples in Ref is the highest because of its strong ability to extract the colour features of murals. Compared with other algorithms, the proposed algorithm also maintains good classification ability when the difference between the inner classes is slight, proving that the network model's performance is better than that of the classical classification algorithm.

Pattern Repair and Reconstruction

Based on the information on the recognized lotus pattern, the image processing and restoration algorithm were used to repair and reconstruct the lotus pattern in the mural further. This includes filling in the missing parts of the lotus pattern, repairing the damaged structure, and adjusting colour and contrast. At the same time, with the help of computer algorithms, the original lotus pattern can be restored more accurately so that the restored murals present a more realistic and complete artistic effect. In the process of mural image restoration, it is necessary not only to learn the features of the mural but also to strengthen the ability to transmit and reuse features between various layers to improve the restoration quality. Damaged Dunhuang murals are generally accompanied by the loss of a large amount of information, and the existing deep learning algorithms often have problems such as weak feature perception ability and loss of reconstruction details when repairing damaged mural images, which affect the restoration effect. This paper establishes the model with dual encoders, and the overall network model framework is shown in Figure 6.
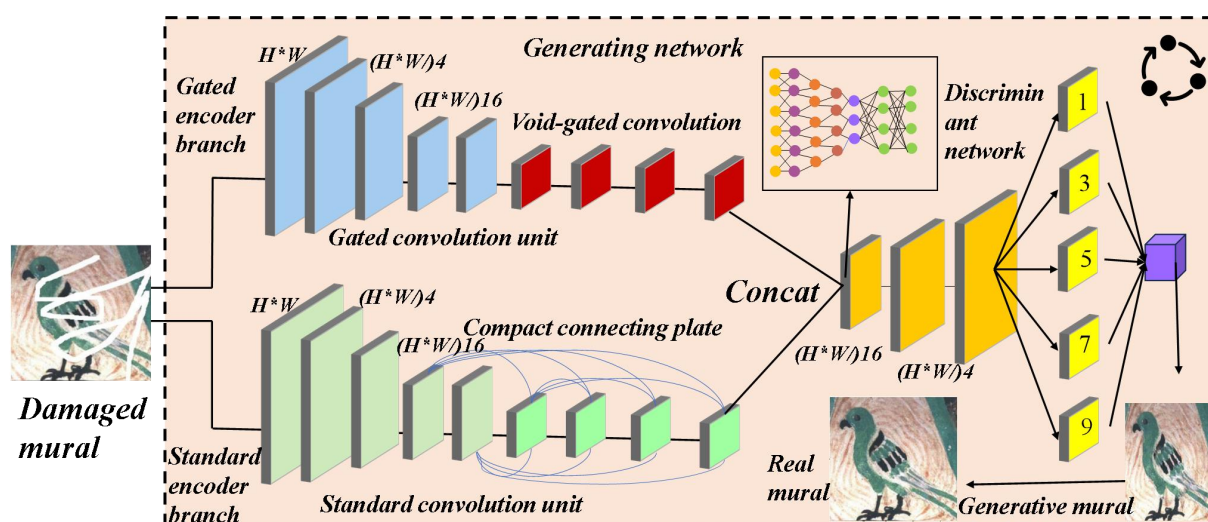
Figure 6. Holistic Network Model Framework

CONCLUSION

This paper analyzes the artistic expression and evolution of the lotus pattern in the Goguryeo murals in Ji'an, and reveals the important position and far-reaching influence of the lotus pattern in Goguryeo culture and art. The following conclusions can be drawn from this:

(1) In terms of artistic expression, lotus patterns in Goguryeo murals show an evolutionary trend from simplicity to complexity and from abstraction to realism. This change not only reflects the improvement of Goguryeo artists' skills, but also the change and development of Goguryeo society's pursuit of aesthetics. Through advanced digital image analysis techniques, we are able to accurately track this evolution, capturing the gradual evolution of styles and expressive techniques in minute artistic details. These technical means allow us to more clearly identify the changes in artistic styles in the murals, and thus to understand the vein of Goguryeo artistic development in greater depth. Second, in terms of cultural significance, the lotus pattern was gradually integrated into Buddhist symbols from the initial nature worship to become a symbol of kingship, a process that demonstrates the cultural diversity and inclusiveness of Goguryeo society. Digital image analysis helps us to reveal how the visual representation of these cultural symbols in the murals evolved over time, revealing how the exchange and integration of foreign and local cultures were manifested through art forms.

(2) In our study of the digital analysis of the artistic expression and evolution of the lotus motifs in the murals of Goguryeo in Ji'an, we used advanced digital image processing algorithms to identify and reconstruct the lotus motifs in the murals in detail. The digital means enabled us to analyze the artistic information of these motifs more accurately, revealing their expressions and stylistic changes in different historical periods. The results of these analyses not only help us to explore the artistic expression and evolution of the lotus motifs more deeply, but also provide new perspectives and methods for the study of Goguryeo murals.

CONFLICT OF INTEREST

There is no conflict of interest to declare for this research article.

REFERENCES

Chen, D., Cheng, P., Simatrang, S., & Joneurairatana, E. (2021, February). Innovative design of caisson lotus pattern in Mogao grottoes based on shape grammar. In *Journal of Physics: Conference Series*, vol. 1790, no. 1, p. 012014. IOP Publishing.

Fang, J., Li, H., Jia, Y., Ji, L., Chen, X., & Wang, N. (2023). Thangka mural style transfer based on progressive style-attentional network and multi-level loss function. *Journal of Electronic Imaging*, 32(4), 043007-043007.

Fang, X., Zhang, B., Li, J., Hu, L., & Chen, W. (2024). A significant comparison between magnesium-based binder and other inorganic cementitious materials for the restoration of brick-carved cultural relics. *Construction and Building Materials*, 411, 134788.

Furtado, L. S., & Payne, J. M. (2023). Inclusive creative placemaking through participatory mural design in Springfield (MA). *Journal of the American Planning Association*, 89(3), 310-323.

Gomoiu, I., Cojoc, R., Ruginescu, R., Neagu, S., Enache, M., Dumbrăvician, M., . . . Ghervase, L. (2022). The susceptibility to biodegradation of some consolidants used in the restoration of mural paintings. *Applied Sciences*, 12(14), 7229.

Gu, W., Wei, Y., Liu, B., Hu, L., Zhong, L., & Chen, G. (2022). Polyacrylic acid-functionalized graphene@ Ca (OH) 2 nanocomposites for mural protection. *ACS omega*, 7(14), 12424-12429.

Guo, A., Lin, E., Zhang, J., & Liu, J. (2024). An energy-efficient image filtering interpolation algorithm using domain-specific dynamic reconfigurable array processor. *Integration*, 96, 102167.

Himmi, M., & Elalamy, Y. A. (2023). Walls of many colors: The celebration of mural art in the Moroccan city. *International Journal of Linguistics, Literature and Translation*, 6(8), 183-190.

Jie, G., & Chaetnalao, A. (2023). Application of motion capture technology in the digital recreation of Tang Dynasty mural art: A case study of Han Xiu's Tomb. *International Journal of Arts and Technology*, 14(4), 298-319.

Lee, H. J., & Chung, Y. J. (2023). Antifungal, antibacterial, and interference effects of plant-extracted essential oils used for mural conservation at Buyeo Royal Tomb No. 1. *Applied Sciences*, 13(6), 3645.

Lee, H. S., & Han, K. S. (2023). Contribution to the understanding of Mural painting techniques of Jinpari tomb No. 4 of the complex of Koguryo Tombs, World Heritage. *Crystals*, 13(3), 459.

Li, H. (2022). The method of repairing OHE damaged ancient painted murals based on machine vision. *Journal of Computational Methods in Sciences and Engineering*, 22(1), 305-319.

Liang, J., Liu, A., Zhou, J., Xin, L., Zuo, Z., Liu, Z., . . . Hu, X. (2022). Optimized method for segmentation of ancient mural images based on superpixel algorithm. *Frontiers in Neuroscience*, 16, 1031524.

Lin, Z., Wu, X., Liao, L., Xu, T., Zhang, Y., & Calia, M. (2022). Application of consumer–level UAV photogrammetry in digital survey of Cliff-Burial culture relics: A case study of Mount Wuyi. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 43, 815-822.

Macchia, A., Castro, M., Curbelo, C., Rivaroli, L., Capriotti, S., Vieira, E., . . . La Russa, M. F. (2021). Methods and products for the conservation of vandalized urban art murals. *Coatings*, 11(11), 1304.

Mezzadri, P. (2021). Contemporary murals in the street and urban art field: Critical reflections between preventive conservation and restoration of public art. *Heritage*, 4(3), 2515-2525.

Moretti, P., Zumbühl, S., Scherrer, N., & Piqué, F. (2024). Traditional and modern pigments in G ino S everini's S wiss murals. *Color Research & Application*, 49(1), 124-143.

Riegl, A. (2020). The restoration of the wall paintings in the Holy Cross Chapel of the Wawel Cathedral in Kraków. *Grey Room*, (80), 50.

Rivaroli, L., Moretti, P., Caricchio, A., & Macchia, A. (2021). Mural art conservation data recording (Scima): The Graart project. *Heritage*, 4(04).

Sun, X., Chen, W., & Zhang, B. (2023). A portable microfluidic device integrated with electrochemical sensing platform for detection of multiple binders in ancient wall paintings. *Analytica Chimica Acta*, 1275, 341562.

Sun, X., Zhang, B., & Chen, W. (2023). Electrochemical chip combined with immunomagnetic beads enrichment for the detection of peach gum binding medium in ancient wall paintings. *Analytical Letters*, 56(18), 2869-2881.

Tang, H., Geng, G., & zhou, M. (2020). Application of digital processing in relic image restoration design. *Sensing*

and Imaging, *21*(1), 6.

Vettraino, R., Valentini, V., Pogliani, P., Ricci, M., Laureti, S., Calvelli, S., . . . Pelosi, C. (2023). Multi-technique approach by traditional and innovative methodologies to support the restoration of a wall painting from the 16th century at Palazzo Gallo in Bagnaia, Viterbo, Central Italy. *Buildings*, *13*(3), 783.

Xu, H., Zhang, Y. and Zhang, J., 2024. Frescoes restoration via virtual-real fusion: Method and practice. *Journal of Cultural Heritage*, *66*, pp.68-75.

Zou, W., & Yeo, S. Y. (2024). Characterization of the influence of the particle size of pigments on proteinaceous binders used in ancient wall paintings following photo and thermal ageing. *Analytical Letters*, *57*(7), 1078-1091.