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Application of Digital Art Technology in Architectural Heritage Preservation and Digital Reconstruction in the Construction Industry

Zheng Qi[1*], Chen Kang[2], Peng Wang[3] and Wei Li[4]

[1,2,3,4]College for Creative Studies, Changzhou Vocational Institute of Mechatronic Technology, Changzhou 214163, Jiangsu, China
[1]qixiaozheng@163.com,[2]zhounan12344321@163.com,[3]fengxw@czust.edu.cn, [4]13915067830@163.com

Corresponding Author: Zheng Qi, qixiaozheng@163.com

Abstract. Modern digital art technology has changed the way of architectural heritage protection and interpretation, and the research of architectural heritage protection workers and related experts in the field of architectural cultural heritage protection lies not only in recording and dissemination, but also in architectural research and value reconstruction. As digital art technology can reconstruct architectural heritage electronically, it provides new research thinking for architectural heritage preservation. Therefore, this paper proposes a digital reconstruction method based on Generative Adversarial Neural Network (GAN) for architectural heritage preservation and restoration. Firstly, the GAN is improved by using U-Net and expanding the sensory field by adding null convolution to fully extract the available information of the architectural heritage images, and a dual discriminative network combining local and global is adopted to ensure the overall consistency of the restored architectural heritage images. In addition, WGAN-GP is utilized to strengthen the network training stability.

Keywords: Digital Art; Architectural Heritage Preservation; Digital Reconstruction; Generative Adversarial Neural Network; Construction Industry
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1 INTRODUCTION

In recent years, architectural heritage structures are constantly suffering from various damages: part of the architectural heritage is aging naturally, and many ancient buildings have been in disrepair for a long time or have become relics [10],[2],[17]. Another part of the ancient buildings suffered from natural disasters including weathering, earthquakes, floods, etc. These natural disasters [7],[20],[12] have caused and will continue to cause irreparable damage or damage to them [8],[18]. In addition, man-made destructive factors such as overuse, war, urban renewal and construction also pose threats to many heritage sites. Especially with the renewal of contemporary urban construction, some buildings will also be rebuilt due to changes in their functions and social aesthetics, resulting in the loss or complete loss of their authenticity; at the same time, due to many factors such as insufficient funds and technical conditions , In the process of physical restoration of traditional architectural sites [3],[1],[25], there are generally certain difficulties and distortion problems, which lead to the unsmooth development of rescue and protection work. With the advancement of science and technology, it has become a trend to apply modern digital art technology to the restoration and repair of historical buildings [4],[6],[5]. This method can not only reduce the cost and difficulty of later maintenance, but also reduce the man-made effects on historical buildings in actual activities. Destruction, to protect the historical value and cultural value of ancient buildings to the greatest extent.

Time is irreversible, different historical buildings have their different character traits, the volume relationship, structural characteristics and material texture of the building body, as well as the artistic characteristics, humanistic ideas and social performance behind the architectural phenomenon, all of which give the ancient buildings a very important significance. However, in the actual physical restoration of buildings, there is often an unavoidable conflict between aesthetics, historiography and technical aspects. Traditional conservation methods tend to hide historical and cultural information such as artifacts, ancient books and other pictorial images that exist behind the physicality of the architectural site in museums, detaching them from the space in which they were originally located, which leads to a separation of the overall concept. At the same time, the information conveyed by architectural heritage is often complex, and the limited physical entity of a site is generally unable to fully express all of its cultural connotations. In terms of the display of architectural heritage, due to the low public awareness and the lack of modern scientific and technological means of intervention, the cultural heritage is displayed in a single way, which is unable to show the full charm of the architecture, and it is difficult to gain a sense of public recognition due to the lack of a sense of cultural experience and interactivity. The spiritual elements that exist behind the buildings to satisfy the inner spirit of human beings and the spiritual elements attached to the material are a loss to the historical information itself if they are not reasonably protected and displayed [9],[21]. The physical information of the architectural site itself, as well as the knowledge, experience and construction techniques inherited in the course of history, need the intervention of modern science and technology and means for better protection, interpretation and display.

The core of architectural heritage protection is to ensure its vitality [23] so that it can fully reflect the value of existence in the modern social environment. Therefore, when a historical building cannot continue to meet the original functional requirements, the best way to protect it is to protect the historical building itself by adding and updating functions that meet the needs of people today. In the rapidly developing contemporary social environment, using high-precision, high-fidelity modern digital art technologies such as augmented reality, artificial intelligence, virtual reality, database and multimedia, to rationally develop and utilize the resources of heritage areas, and integrate the historical and cultural heritage contained in them. The combination of resources and commercial management is an effective way to promote the sustainable development of heritage regional culture and economy. Combining digital art technology to develop practical auxiliary systems or means based on computers and the Internet, thus contributing to the sustainable development of cultural heritage. By integrating heritage-related audio, documents, images, and videos, it provides new functions such as digital preservation [13], recording, and retrieval [16],[10], so as to further build a digital cultural heritage museum. At the same time, the protection of architectural heritage based on digital art technology will greatly stimulate the tourism industry, and play an important role in preserving the historical significance of buildings, enhancing users' understanding of culture, and providing positive publicity resources.

Therefore, combining digital information and network technology to build a new form of cultural tourism to highlight the value of digital architectural protection in economic, social, cultural, historical, and educational aspects. For example, by constructing an architectural space that combines virtual and real, the attractiveness of cultural heritage attractions can be improved, and tourists who want to have a deeper understanding of architectural sites can be attracted, so that their specific cultural content can be widely disseminated in a modern market environment, and the economic viability of heritage areas can be promoted. Continuous development; at the same time, architectural space can also be combined with students' teaching classrooms for the teaching and dissemination of architectural historical knowledge, the purpose is to better protect historical relics and their carrying Cultural values, thereby maintaining tradition, history and cultural continuity.

The main contributions of this paper are as follows:

1. Digital art technology can reintegrate complex spatial information in architectural heritage, and make the historical culture behind architectural heritage tangible and contextualized, so as to make up for the shortcomings in the existing digital protection of cultural heritage. By combining the core of human-oriented interactive design, it provides interactive digital architectural heritage protection and reconstruction for experiencers.

2. In this paper, we propose a dual-discriminant generative adversarial network for restoration and reconstruction of architectural heritage. Among them, the generator is improved on the basis of U-Net, and the hollow convolution is added to expand the receptive field, and the available information of the architectural heritage image can be fully extracted, and the dual discriminant network combining local and global is used to ensure the overall consistency of the restored architectural heritage image sex. In addition, WGAN-GP is used to enhance network training stability.

2 RELATED WORKS

2.1 The Need for Architectural Heritage Preservation and Digital Reconstruction

The introduction of digital art technology in the protection of architectural cultural heritage plays a prominent role in preserving architectural cultural significance, providing integrated information for the research of architectural professionals, improving tourist satisfaction, strengthening school architectural education and public cultural promotion. The following will explain the needs of introducing digital art technology from the aspects of architectural cultural heritage's own value, protection principles, protection work and the public. (1) Self-worth needs. Modern anthropologists believe that human concepts, values, behaviors and even emotions can be regarded as the product of culture. As such, buildings created throughout human history are unique cultural products. As a non-renewable resource, historical buildings have their unique information value, emotional value and utilization value. However, due to environmental and man-made damage, the information it contains is constantly decreasing. Combining MR technology to preserve and fully display the information of historical buildings is of great significance for us to understand the meaning of cultural heritage, research and understanding of protection methods. (2) Protection principle needs. The importance of following the principles of authenticity, integrity, accessibility and sustainability is emphasized in the protection of cultural heritage. In the "Nara Authenticity Document", the importance of the credibility and reliability of the original materials is emphasized, and cultural diversity exists at both the time level and the space level, so for architecture, its authenticity needs to be based on different historical period or the entire history of the situation. The architectural site is a complex complex, and its many elements, such as the location of the architectural site itself, design style, material technology, emotion and atmosphere, etc., have established a certain connection with the surrounding environment, which is an organic overall. In the nomination process to UNESCO's World Heritage List, authenticity concerns the design, materials, craftsmanship and surroundings of the site. MR technology can analyze the architectural site from the perspective of art and cultural experience, show the aesthetic and historical characteristics of the site, show the material, social, historical background, and the use and function in a certain social situation, etc. Fully demonstrate the principles of architectural integrity and authenticity in terms of time and space. (3) Protection work needs. Due to the rapid development of society, people have put more thinking and attention into modern protection work, people are paying more and more attention to the relationship between nature and the environment, and their awareness of the history of cultural heritage and sustainable development has gradually deepened. The "Venice Charter" also stated: "The protection and restoration of historical buildings must rely on all science and technology that can provide support for the research and protection of architectural heritage." The conservation of architectural heritage is closely related to contemporary science and technology. At the same time, conservation experts have gradually shifted their focus from architectural "restoration" to historical and cultural research on architectural sites as a whole. Digital art technology provides a new research method for cultural heritage protection. It can not only provide a more convenient way of information integration and presentation, but also provide various virtual research tools to simulate the operation of actual skills, thus solving the traditional research process. various conditions that may exist. For example, in view of many problems such as the inability to observe the internal structure of the building, the limitation of the observation position and angle, and the lack of research tools, digital art can be combined to allow the staff to fully obtain the three-dimensional space information of the building during the research process, and quickly retrieve the information. At the same time, we can perceive architectural entities more intuitively and vividly, and carry out relevant research work with a full understanding of architecture at the time and space levels. (4) Public needs. With the development of the economy, people's material life is constantly improving, and the demand for spiritual life is increasing day by day. Therefore, the architectural cultural heritage with historical and cultural connotations, artistic characteristics, and traditional Chinese characteristics has attracted more and more public attention. At the same time, cultural creations and cultural services with cultural characteristics combined with modern digital technology are increasingly favored by the public. The diversity of cultural creations is considered a priority by UNESCO, as well as by the international community as a whole. Today's increasingly prominent needs for the protection and utilization of education, cultural tourism resources, and dissemination of information exchanges require modern protection to integrate architectural site entities and their potential cultural attributes, surrounding environment and material resources, and use digital technology, etc. Necessary technology and capacity building by means of modern scientific and technological protection, as well as related building maintenance and development and utilization of heritage areas [22].

2.2 Generative Adversarial Networks

Generative Adversarial Network Since it was proposed by Ian Goodfellow [11] and other scientists in 2014, the generative model has received a milestone breakthrough. Unlike general generative models, the overall structure of this network is divided into two networks, the generator network G and the discriminator network D. The specific structure is shown in Figure 1.

The proposal of GAN combines the Nash equilibrium idea of game theory, and its training process can be regarded as a dynamic game process between G and D. In the training phase, the generator uses the input random noise vector z to try its best to generate an image $G(z)$ similar to the original image, and sends it to D. The discriminator is actually a binary classifier, which continuously learns the feature information of the real image to Identify the authenticity of the generated image and feed back the result to the generator.

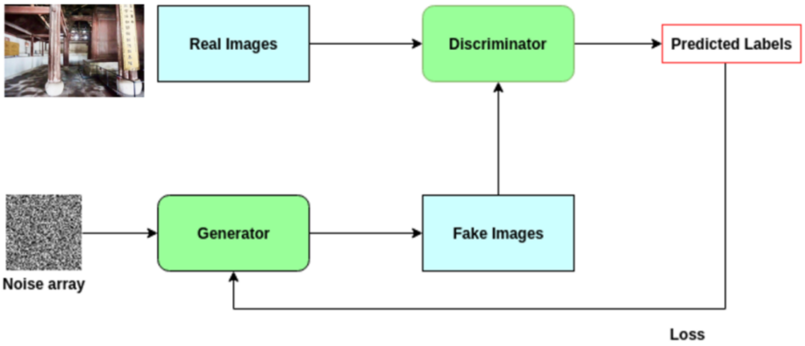

Figure 1: The Basic Structure of Generative Adversarial Networks.

This process is a continuous cyclic confrontation process. Both G and D optimize their generation ability and discrimination ability based on the discrimination results, and continuously improve the quality of $G(z)$ until D thinks that $G(z)$ is no different from the real image, and the training ends. The model at this time reaches the best performance, the generator can generate images that are very similar to real images, and the discriminator has an excellent discriminative level. The objective function of GAN is as follows:

$$\min_G \max_D V(D,G) = E_{x\sim P_{data}(x)}[\log D(x)] + E_{z\sim P_z(z)}[\log(1 - D(x))] \tag{1}$$

Where x represents real data, $p_{data}(x)$ represents the distribution of real data, z represents the noise vector data input by the network, and $p_z(z)$ represents the distribution of noise vector data.

Many studies have shown that GAN has shown excellent performance in various fields such as image inpainting, image super-resolution reconstruction, image recognition. However, in actual training, it is difficult for the generative adversarial network to achieve the Nash equilibrium state, and there are still many limitations, such as the instability of the training process that makes the network difficult to converge, gradient dispersion, and model collapse.

2.3 Image Restoration

Figure 2: Schematic Diagram of Image Restoration of Architectural Heritage.

Digital image restoration [15] of architectural heritage refers to the process of utilizing the correlation information of the adjacent undamaged areas of the damaged areas of the image, choosing a certain way to generate suitable information and filling it into the damaged areas to obtain a complete image. In practice, by covering the mask image on the original image to simulate the area to be repaired, and then take the restoration model for repair, to obtain a complete image visually similar to the original image with natural structure and real texture, the process is shown in Figure 2. Among them, the mask image is generally a black-and-white image, and (0,1) matrix representation, 0 represents the damaged area, 1 represents the undamaged area. The formula can be expressed as follows:

$$I_M = I_R \odot M, I_M \in (\Psi \cup \Phi) \tag{2}$$

Among them, I_M and I_R represent the image to be repaired and the original complete image after adding the mask, M is the binary mask, Ψ and Φ refer to the undamaged area in the image (the black area in the mask) and the area to be repaired, respectively (white area in mask).

3 METHODOLOGY

Architectural heritage images [14] are different from ordinary images, and the texture features they contain are often complex and changeable, and they are closely related. When using the existing deep learning methods to directly repair architectural heritage images, many problems need to be solved, such as the loss of feature information, and when repairing large-scale damage, the repair results may be inconsistent with the local and global problems. For the above problems, this paper proposes a dual-discriminant generative adversarial network model for architectural heritage restoration, which is used to realize virtual restoration and digital reconstruction of architectural heritage images.

3.1 U-Net

The U-Net network [19] is a fully convolutional network with a symmetrical U-shaped structure, as shown in Figure 3. This structure is a typical encoder-decoder (Encoder-Decoder) structure, in which the two parts of the ordinary convolutional layer and the pooling layer constitute the Encoder structure, that is, the contraction path of the left half, and feature extraction is performed through 4 layers of downsampling operations; The extension path in the right half is the decoder, which is composed of a deconvolution layer. It uses 4 layers of upsampling to restore the image to its original resolution. At the same time, the two are connected by a Skip Connection for fusion and stitching of low-level features. map and high-level feature map, so as to retain more useful information of the image.

3.2 Bi-Discriminative Generative Adversarial Network Algorithm

In this paper, the generative adversarial network is the main framework, which is realized by the generative network and the double discriminative network with double branching structure, and the overall framework is schematically shown in Figure 4. Among them, the generative network is composed of similar U-Net structure, which utilizes Skip Connection to extract deep detail feature information. At the same time, the number of up-sampling and down-sampling operations is reduced to retain as much original detail information as possible, to ensure that the generative network generates images as similar as possible to the broken region.

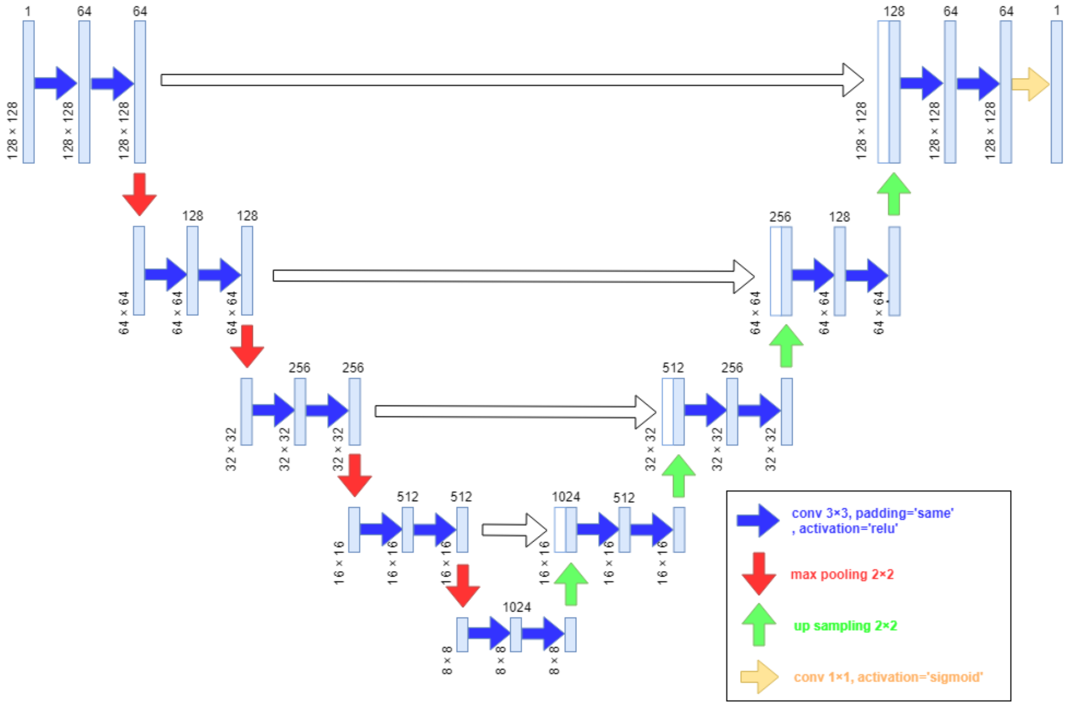

Figure 3: U-Net Network.

The generated results are then fed into the dual discriminative network to discriminate separately, aiming to ensure the local consistency of the repaired damaged area and its surrounding areas as well as the global consistency of the overall image. The two are constantly optimized against each other to finally achieve the repair of the texture and overall structural consistency of the damaged area of the mural.

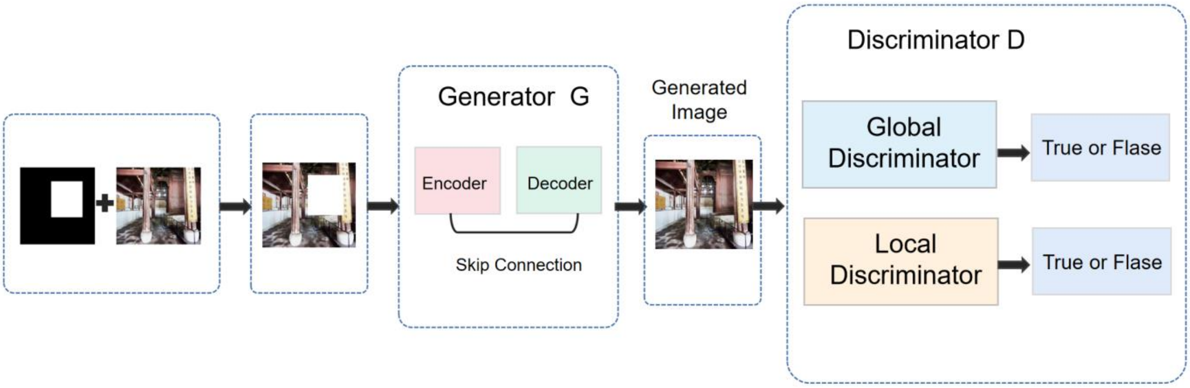

Figure 4: Overall Framework Diagram.

1. Generator Architecture

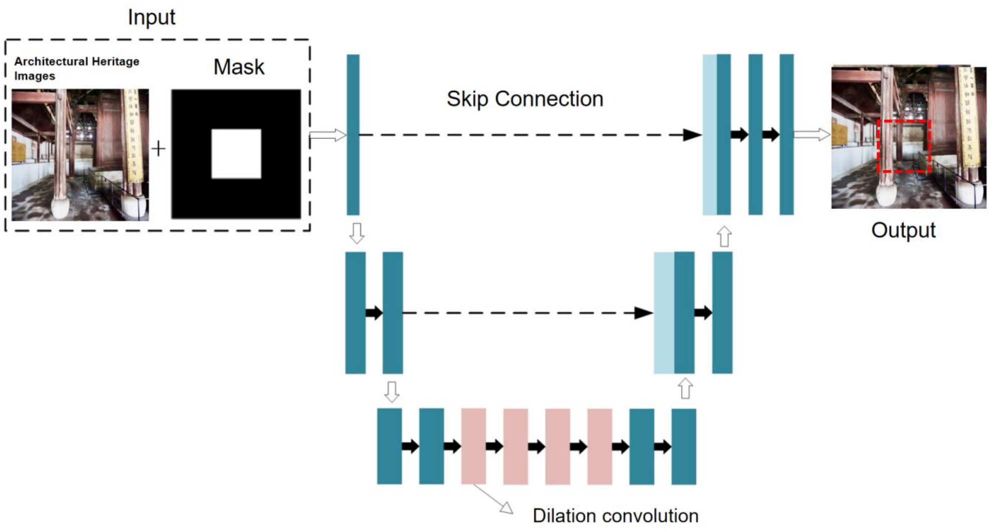

Figure 5: Generate Network Structure Diagram.

U-Net was initially applied to medical image segmentation task because of the small amount of data and difficulty in collecting medical images, and U-Net can effectively solve the unsatisfactory training effect caused by the small amount of data. As with medical images, there is a scarcity of accessible mural images, coupled with the fact that U-Net's hopping connections preserve low-level features and its U-shaped structure allows the model to learn deep high-level semantic information, which is conducive to the generation of finer details. Therefore, the generative network uses a U-Net-like architecture as its main structure, with the aim of generating mural images that have realistic textures, are similar to the original image, and have a consistent image contextual structure. consistent mural images. The structure of the generative network is shown in Figure 5.

The implementation of the generative network is as follows: a mural image of size 128*128 is fed into the generative network together with a randomly generated mask, which ranges from 24-56, and then a modified encoder is used to extract enough useful information and learn the image features sufficiently, and then decode the feature maps through a decoder, which generates the missing regions of the image and maps the image to its original size. The generative network is only responsible for generating the content of the missing regions, the intact regions are not altered, and the two are combined to get the final generated image. In the traditional U-Net network, the feature extraction process is realized by Max-pooling operation, but the feature map will filter out some structural and detailed feature loss after many pooling layers, so this paper adopts the convolution operation with a step size of 2 instead of Max-pooling as the downsampling method, so as to obtain the main features of the image. Similarly in the decoding stage the inverse convolutional layer is utilized to achieve upsampling so that the image can be obtained with finer information such as edge structure. However, the size of the image is reduced by downsampling and then recovered by upsampling and re-expanding, a process that often results in the loss of a large amount of image information, which affects the realism of the generated image, and therefore, in this chapter, only two upsampling and downsampling are performed. In addition, 4 layers of null convolution are added to the generative network to effectively widen the sensory field range, so as to obtain a larger range of structural features while reducing the loss of available information.

2. Discriminator Architecture

For GAN, the generator and discriminator depend on each other in the training process, and one side is too strong will affect the training of the overall model. Therefore, it is also necessary to improve the design of the discriminant network, and the structure of the improved discriminant network is shown in Figure 6. The two discriminative networks used in this chapter are the local discriminator and the global discriminator, which are designed to recognize the gap between the generated image and the original image, and gradually reduce it in the process of fighting with the generated network. The local discriminator is used to improve the authenticity of the restored region, and the global discriminator is used to ensure the visual overall consistency between the restored region and the intact region. Both of them have a simple structure, except for the different number of convolutional layers, which consists of convolutional layers, Leaky-ReLU activation function.

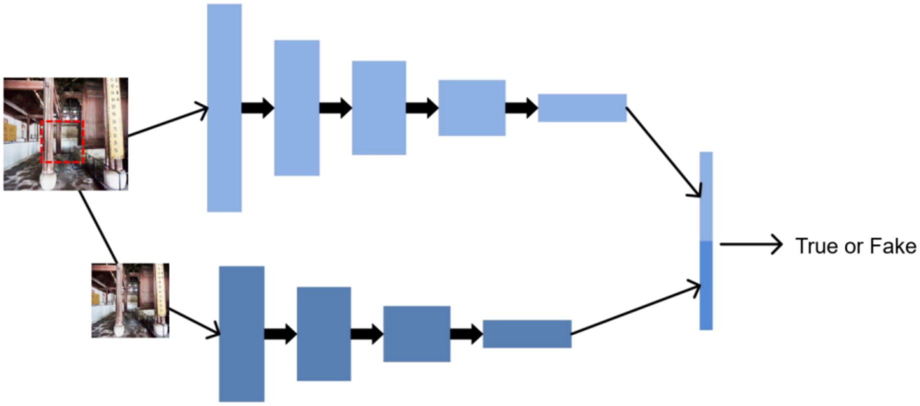

Figure 6: Dual Discriminant Network Structure.

3.3 Loss Function

The loss function is used in deep learning to evaluate the difference between the output value of the model and the original value, the smaller the value means the smaller the gap between the two, indicating that the performance of the network model is also better. The selection and design of the loss function determines to a certain extent how well the whole model is trained, and if the loss function in the network is not used properly, it will lead to the network not converging properly, thus not achieving the desired generation results. In this chapter, a joint loss function of the reconstruction loss function and the adversarial loss function is used to optimize the network model and ensure the consistency of the repaired area with the overall image.

The reconstruction loss is used to measure the deviation within the corresponding region of the generated image and the real image, and the mean square error function (MSE) is chosen as the reconstruction loss for this network, which is defined as the function:

$$L_{mse} = \frac{1}{M}\sum_{m=1}^{M}\left(P_{\text{data}}(y_m) - P_z(y_m)\right)^2 \tag{3}$$

Where M is the training dataset of architectural heritage images, $P_{data}(y_m)$ is the input image and $P_z(y_m)$ is the output image. The generative network can generate rough structure as well as color information by using reconstruction loss, so that the generated architectural heritage image is constantly close to the real image, and then more detailed detail information can be generated by fighting against the loss.

The training process of the original generative network exists that the discriminator is in the optimal state but cannot update the gradient, which leads to unstable training and network crash. In order to solve this problem, researchers proposed WGAN with Wasserstein distance, but WGAN can only realize weight trimming according to the fixed weight range defined by the experimenter in advance, which limits the expressiveness of the network to some extent. Therefore, the researchers further extended the study by discarding the weight trimming operation and proposed WGAN-GP that sets an independent penalty term for each sample to improve the objective function and make the network performance more stable. Therefore, in this paper, WGAN-GP is used as the adversarial loss function with the following equation:

$$L_{adv} = \underset{x\sim p_g}{E}\left[D(x)\right] - \underset{x\sim p_r}{E}\left[D(G(z))\right] + L_{gp} \tag{4}$$

$$L_{gp} = \lambda \underset{\hat{x}\sim p_{\hat{x}}}{E}\left[\left(\left\|\nabla_{\hat{x}} D(\hat{x})\right\|_2 - 1\right)^2\right] \tag{5}$$

where x denotes the real image, z denotes the region to be repaired, and L_{gp} is the gradient penalty, which is set to make the gradient satisfy the Lipschitz limit. Since this paper uses a dual discriminant network, the joint loss function of the network is:

$$L = \lambda_1 L_{mse} + \lambda_2 L_{g_{adv}} + \lambda_3 L_{l_{adv}} \tag{6}$$

4 EXPERIMENT AND RESULTS

4.1 Experimental Settings

The hardware environment for the experiments in this chapter is a Core(TM)i5-10400F@2.90GHz CPU processor, an NVIDIA GTX 1080 graphics card, and 16GB of RAM. The software configuration environment used is: Windows 10 operating system, using Python3.6 programming language, under the PyCharm compiler, using the Tensorflow-gpu1.14 deep learning framework and related library functions to complete the construction of the model. In order to verify the effectiveness of the algorithms in this chapter for restoring the defective mural images, the models in this chapter as well as the models used for comparison are carried out in this experimental environment. In the experiments of this chapter, the Adam algorithm is used to optimize the parameters of the restoration model, with Learning rate set to 0.002 and Batch size set to 8.

4.2 Dataset

In deep learning, ensuring a sufficient number of training samples is one of the key issues. When training neural networks, the dataset requirements are high, and with a sufficiently large sample size, the richer the type, the more conducive to improving the model accuracy. In the case of a small sample size and a single type, the model is extremely prone to overfitting problems. To prevent this type of problem, this chapter uses an image data enhancement algorithm to effectively expand the architectural heritage image dataset, provide sufficient sample size for model training, and improve the generalization ability of the model. Due to the fact that there is no publicly available and standardized architectural heritage image dataset, coupled with the fact that the number of extant intact architectural heritage available is not large, the quality varies, and the subject matter styles are different. In this paper, architectural heritage images are first collected and then expanded using image data enhancement algorithms in order to complete the construction of architectural heritage image datasets.

4.3 Experimental Results and Analysis

In order to verify the effectiveness of the restoration and reconstruction model constructed in this paper, a test set of architectural heritage images is used and a random mask is generated for test analysis. At the same time, another 1 classical and GAN-based image restoration algorithm is selected as the experimental results for comparison, and finally the restoration results are evaluated by combining subjective and objective evaluations. The comparison results are shown in Figure 7.

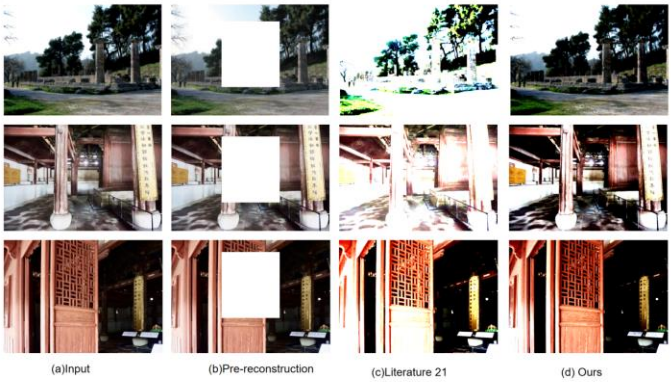

Figure 7: Comparison of Repair Effects of Different Algorithms.

From Figure 7, it can be seen that the repair results of the literature [24] method have serious texture blurring phenomenon, and many mask block artifacts remain in the repaired area, and the quality of the repair and reconstruction results is poor. In contrast, the algorithm in this paper has further improved in structural continuity and texture details, and can basically accurately restore the original part for the larger broken region, with better visual connectivity.

	literature [21]		*Ours*	
	PSNR	*SSIM*	*PSNR*	*SIM*
1	*31.26*	*0.885*	*33.96*	*0.889*
2	*26.17*	*0.781*	*30.26*	*0.915*

3	*27.69*	*0.811*	*31.69*	*0.905*
4	*30.71*	*0.856*	*33.94*	*0.916*
5	*29.25*	*0.587*	*32.58*	*0.899*
6	*26.35*	*0.812*	*30.69*	*0.882*
7	*27.26*	*0.795*	*29.69*	*0.872*

Table 3: User Experience Satisfaction in Virtual and Real Environments.

In order to make the test results more fair, this paper randomly selects 7 images in the test set, with different sizes of masks to indicate the different degree of breakage, using different algorithms as well as this paper's algorithm to repair in turn, and quantitatively evaluates them with two objective evaluation indexes, PSNR and SSIM, and the evaluation results are shown in Table 1. From the data in the table, it can be concluded that the PSNR and SSIM values of the experimental results are higher than those of the comparison algorithms, which indicates that the performance of this algorithm is better and the quality of the repaired images is better.

5 CONCLUSIONS

In this paper, we proposes a digital reconstruction method based on Generative Adversarial Neural Network (GAN) for the preservation and restoration of architectural heritage. First, the GAN is enhanced by incorporating U-Net and expanding the sensory field by adding null convolution in order to fully extract the available information from the architectural heritage images. Next, a dual discriminative network combining local and global features is adopted to ensure the overall consistency of the restored architectural heritage images. In addition, WGAN-GP is utilized to improve the stability of network training. The experimental results demonstrate that the proposed generative adversarial neural network (GAN)-based digital reconstruction method is able to reconstruct and repair architectural heritage images more effectively, thereby providing new insights for the preservation of architectural heritage.the application of digital art technology in architectural heritage preservation and digital reconstruction in the construction industry offers numerous benefits, including improved accuracy, visualization, collaboration, and public engagement.

Zheng Qi, https://orcid.org/0009-0007-5759-8225
ChenKang, https://orcid.org/0009-0009-5020-2202
Peng Wang, https://orcid.org/0009-0004-3751-5363
Wei Li, https://orcid.org/0009-0009-3610-9992

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