Article

CGAN Assists the Styles & Features Renovation of Street Facade—A case study of Wuyi area in Fujian, China

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Abstract: With the development of society and the economy, the unified planning of architectural style has become a difficult problem in the competition between urban expansion and the protection of traditional buildings in villages and towns. At the same time, it also allows people to re-examine the appearance and quality of life of traditional village buildings. In this paper, the Conditional Generative Adversarial Network (CGAN) is used to construct a method of building facade generation in villages and towns, so as to gradually realize the governance of the style of villages and towns. At the same time, it has also reduced the restoration of the facades of villages and towns and the graphic design of rural tourism products, showing its application value and potential in the field of planning and design. In the research, taking villages and towns in the Wuyishan area of China as an example, the method is used to carry out model training, image generation, and comparison of the derivation results of different assumed building contours and product contours. The research shows that: (1) CGAN can be used to derive and design the facades of conventional civil buildings in villages and towns. (2) In terms of product graphic design, especially the common tourist cultural products fans and water cups, show significant potential. (3) The construction of this method is not only applicable to villages and towns under the World Heritage City, but can be further promoted and used in the future for cities and villages that have a demand for architectural style consistency.

Keywords: CGAN; Styles & Features Renovation; Street Façade; world heritage city; Wuyi area

1. Introduction

The world's natural heritage and world cultural heritage are precious resources of mankind. In the face of the rapid development of urban modernization, large-scale modern buildings or strange-shaped buildings emerge in an endless stream. On the other hand, it is inevitable that a large amount of public transportation, such as high-speed railways, needs to be built on the premise that the city needs to develop. In traditional village buildings within the field of vision along the high-speed railway, the coordination and unity of building facades has become the core issue. The unified management and control of the architectural style of hundreds of villages and towns requires designers to spend a lot of time and energy. Therefore, how to control the coordination and unity of traditional village architectural styles and improve the efficiency of architects in the street face of a large amount of repeated design work is a question worth exploring.

1.1 Research background

The Wuyi Mountains are located between Wuyishan City of the Nanping prefecture in northwest Fujian province, and the town of Wuyishan within Shangrao city in northeast Jiangxi province. The mountain range is known worldwide for its status as a refugium for several rare and endemic plant species, its dramatic river valleys, and the

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abundance of important temples and archeological sites in the region, and is a UNESCO World Heritage Site[1]. There are three peaks, known as “Jiageng Style”, “Wuyi Style” and “Regional High-tech Building”, in the development of Fujian regional architecture since 1950s[2]. Around the Wuyi area with Wuyi Mountain as the core, many buildings with regional styles were born, and formed a local architectural school in Fujian, China. The narrow sense of “Wuyi style” refers specifically to the buildings with local characteristics of Wuyi Mountain, which have been recreated by architects in the Wuyi Mountain area after 1979 and now, by absorbing local traditional architectural styles and combining local natural and cultural resources recognized as UNESCO World Heritage Site and specific environments with modern design techniques[3]. At the same time, the Wuyi style emphasizes the integration of architecture into nature, that is, the integration of architecture and natural mountains, and thus promotes the formation of world heritage.The Wuyi style responds well to the call for “modernization of vernacular architecture”, and it is one of the representative works of new vernacular architecture. The unification of its overall architectural style is conducive to the sustainable development of the world heritage city.

1.2 Literature review

There are many design practices in China for the renovation and restoration of architectural style. In terms of specific applications, the representative ones are: Dali ethnic characteristic town in Yunnan[4], historical town in Hubei Province[5], historical landscape along the river in Jiangsu Province[6], traditional village landscape in Henan Province[7], and historical and cultural district in Shanghai[8]. However, they tend to be architects to execute all the schematic designs, spend a lot of time and effort, and potentially duplicate unordered work. Although the style of traditional buildings can guide the transformation of the urban landscape, it also challenges architects to comprehensively consider the transformation plan from the perspective of understanding history and presenting it in the design. It is a time-consuming task for architects to gather local information on a macro-city scale and organize important information. However, dealing with buildings with different urban backgrounds in the face of different historical areas requires more expertise and experience[9].

On the other hand, it is inevitable that in architectural design, individuals have diverse understandings of architecture. The design process will subtly add personal preferences, and this spontaneous development often leads to the loss of the regional cultural characteristics of the building, thus affecting the coordination of the overall style of the streets. Therefore, a design method based on objective information is needed to reduce the influence of individual design on street style [10]. Traditional architectural design is a time-consuming and labor-intensive process. With the advancement of computer technology, machine learning, as the core content of artificial intelligence, provides innovative methods for the above process: (1) Image recognition helps to quickly identify elements in architectural images, thereby realizing batch extraction and evaluation. (2) Image generation and image conversion help to efficiently generate new architectural images and perform style transfer on existing buildings. The above methods have shown great potential in the field of architecture, such as building facade generation [11], building volume generation [12], building floor plan optimization [13], street view quality assessment [14], street view image generation [15], Architectural style migration [16]. All of them can greatly improve the efficiency of building evaluation and building design.

Among them, in the field of building facade generation, the current research is mainly based on the Generative Adversarial Network (GAN) [17]. Artificially mark the elements of the building facade with color blocks as a color block map, and then conduct confrontation training between the building facade image and the color block image, so as to realize the ability of the machine to generate the building elevation map through the color block map [18-19]. This method is suitable for stylistic assessment and façade res-

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toration of existing buildings. However, in the architectural design stage, how to guide the design of the building façade, generate the building facade through the given design scope, and conform to the coordination of the surrounding style of the site, still needs in-depth research.

1.3 Problem statement and objectives

In October 2016, the Nanping Municipal Government clearly stated that the environment and landscape along the high-speed rail and expressway are the windows to display the urban and rural features and social civilization of northern Fujian. It is an important part of the construction of a national green development demonstration zone", which requires the improvement and landscape construction of the environment along the high-speed rail, expressway, 303 expressway, and light rail (Figure 1). Nanping City has also issued policy documents many times to create a landscape with northern Fujian characteristics. The Wuyishan Municipal Government has also set up a leading group to strengthen environmental improvement and landscape construction. The remediation scope includes high-speed rail, expressway, 303 expressway, and light rail within Wuyishan city; the planned expressway section is mainly three sections, namely: (1) G1514 expressway, the junction of Fujian and Jiangxi (279) to Xingtian hub (232) a total of 47 kilometers. (2) G3 Expressway, Wufu Section (Tangbian to Chatouling), a total of 12 kilometers. (3) S0311 expressway, Xiaba hub connects Hongqiao Village for a total of 10 kilometers. All the villages in the visible area along the line and the rural landscape along the line that affect the village style are the targets of remediation (Figure 2).

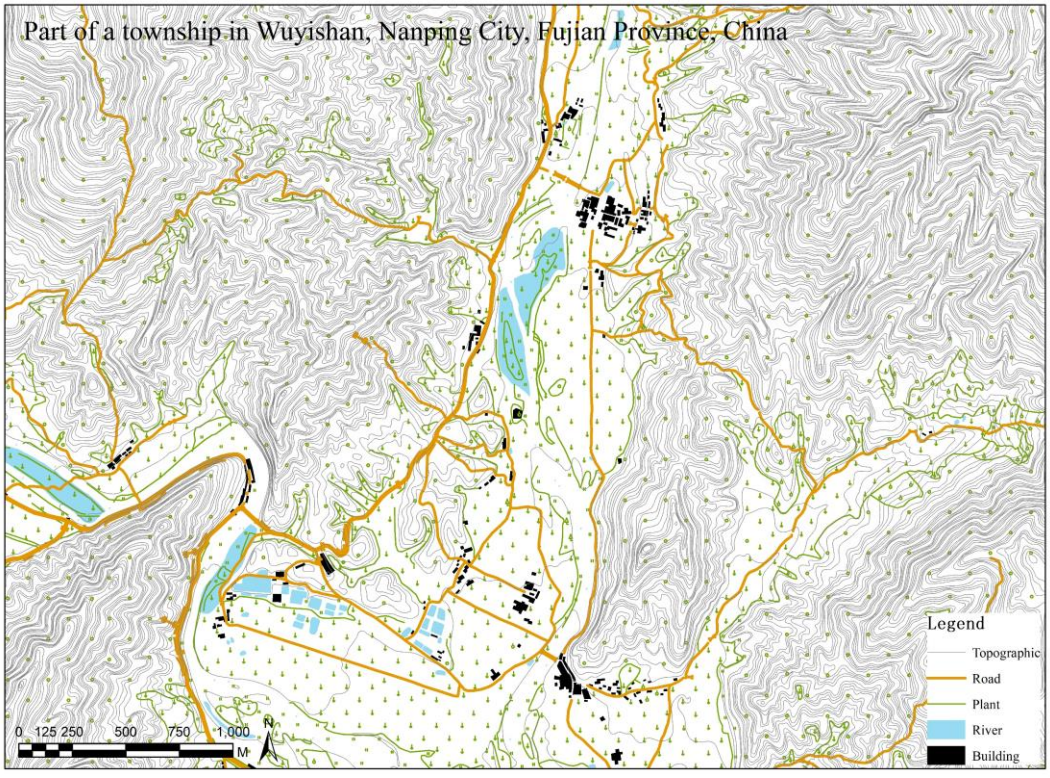

Figure 1. Remediation target area.

Due to the large range of villages to be rehabilitated, it is necessary to maintain the consistency of the traditional urban dwellings. This study explores the technical methods of machine learning to assist in the completion.

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Figure 2. Village view along the way.

2. Materials and Methods

2.1 Methodology

This paper proposed a method based on CGAN to realize the style transfer from the local architectural style to the village and town building facade, and provide the new design, decoration and restoration of the building facade for the village and town architectural style (Figure 3). It has important practical value for the unified-style governance of large-scale and multi-building villages and towns. The method of this study consists of five aspects: data collection, data processing, model training, model evaluation, and data application. The specific contents are as follows:

(1) Data copturing. First of all, it is necessary to clarify the positioning and goals of the village and town street style renovation, that is, what kind of village and town we want to turn into. In this study, through several field investigations and village interviews, he learned that the site has a profound regional culture. The Wuyi style is a characteristic architectural style in this area, but most of this style is located in tourist areas, and economically underdeveloped villages and towns have not yet been fully popularized. Therefore, the researchers photographed and collected 164 Wuyi-style buildings in the tourist area where Wuyi-style buildings were concentrated as samples for the experiment.

(2) Data processing. As a cutting-edge machine learning model, CGAN has powerful image information processing capabilities and realistic generation effects. However, the training of CGAN is often accompanied by problems such as difficulty in convergence and uncontrollable results [20]. In order to reduce the training time of the model and improve the accuracy of the model, we redrawed the collected samples into three categories of pictures: building exterior profile (BEP), functional segmentation layout (FSL), and building elevation (BE).

(3) Model training. In this step, the conditional adversarial generative network is trained with paired images. Therefore, the three types of pictures after data processing are respectively trained from building exterior profile to functional segmentation layout and functional segmentation layout to building elevation, corresponding to two weight models, models 1 and 2. These two models cover all the data to generate building elevation from building exterior profile, which can effectively achieve the experimental goals.

(4) Model evaluation. After the training is completed, the weight model needs to be evaluated and tested to determine whether the model meets the expectations of the experiment. By looking at the Loss and pictures of the training process, you can make a basic judgment on the accuracy of the model. The CGAN Loss value line chart shows the stability of the generator and discriminator during the training process. For better training results, the loss value will continue to decline and stabilize within a small period. In

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addition, pictures of the training process can be seen to see if the generator produces image noise. This kind of image noise is likely to fool the discriminator's true and false judgment, thus showing a good result in the loss of value, but the actual effect of the generation is poor. Through the above two judgment methods, it is possible to control in real time during the training process. If the loss value continues to rise or the effect of the training process becomes worse and worse, the training will be stopped in time, and the training samples and various parameters will be readjusted.

(5) Data application. The model after training can be applied to many aspects of the remediation of villages, towns, streets and alleys. Such as the façade design of new buildings and the façade decoration and restoration of old buildings, and at the same time, analyze and judge the effectiveness and feasibility of these applications.

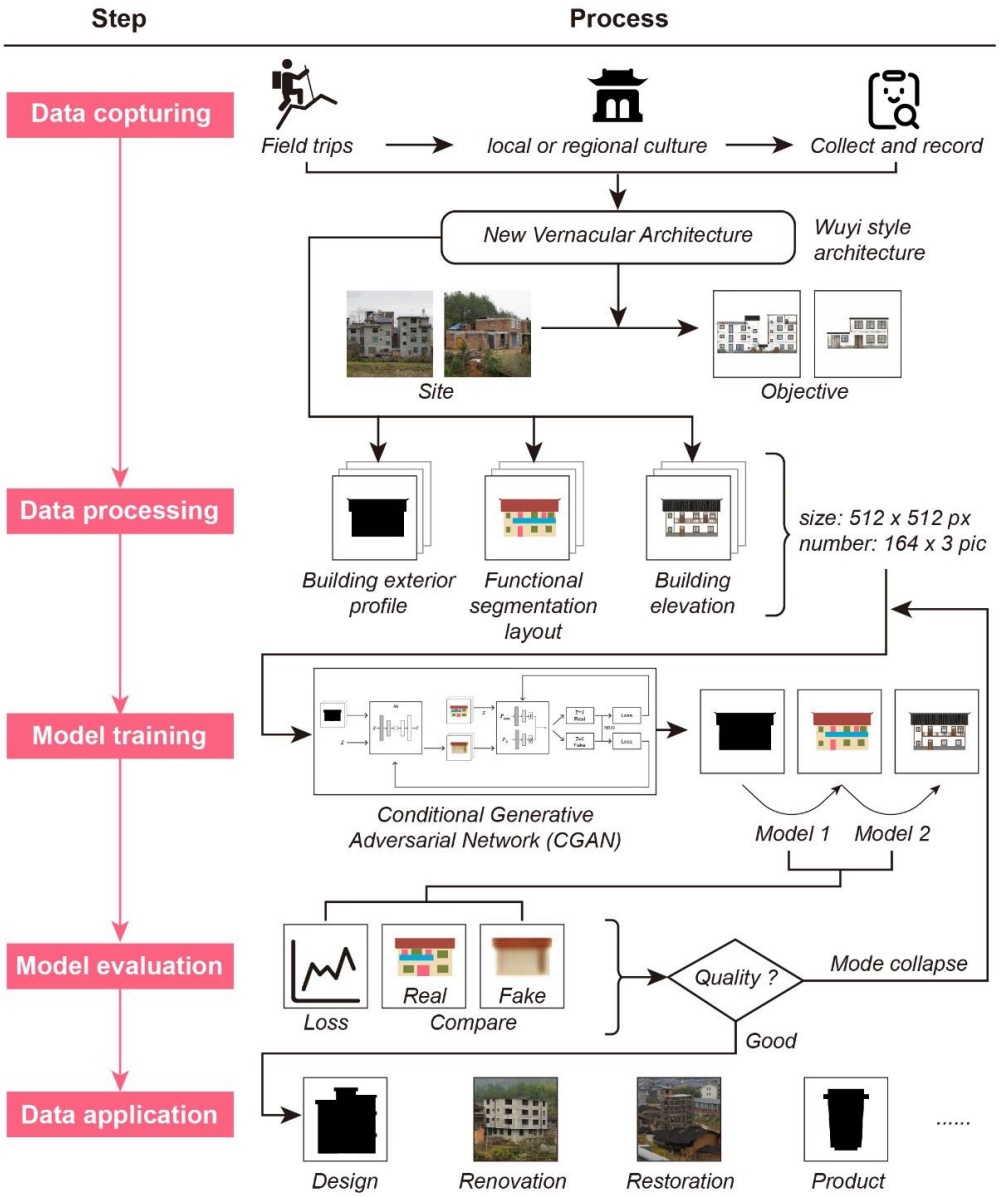

Figure 3. Research methods.

2.2 Materials Handling

A sample of the test material was conducted by the researchers through field research. The buildings around the collection site conform to the regional style of the area, including Wuyi Mountain Villa, Song Street, Jade Girl Villa, Jiuqu Hotel, and Wuyi Style

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Commercial Garden. It covers 32 building groups and 256 individual buildings, from which 164 representative facade pictures are selected. According to different building heights and widths, uniform scaling is performed in 512 × 512 pixel images for registration.

The experimental materials are shown in Figure 4. According to the needs of the experiment, the facade picture is further divided into building exterior profile (BEP), functional segmentation layout (FSL), and building elevation (BE). There are 164 images in each category, for a total of 492 images. The BEP samples are grayscale images with black color (R0, G0, B0). In the processing of FSL samples, in order to simplify the data, various elements in the building facade are represented in different colors and presented in the form of color pictures. In this study, 5 colors are used to represent the elements in the façade, namely, the doors are red (R255, G99, B128), the windows are green (R123, G132, B61), the walls are yellow (R243, G219, B181), and the guardrails are Blue (R3, G172, B213) with a brown roof (R171, G73, B64). These 5 colors can represent most of the content in the building facade. The BE sample is cleaned and simplified according to the actual situation, the unnecessary advertising signs and pollutants in the facade are cleaned up, and the texture of the material is simplified.

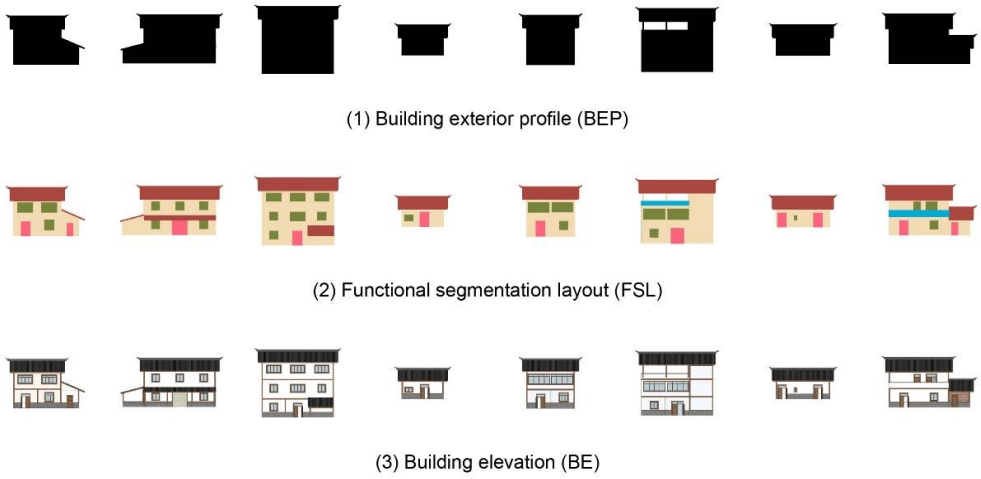

Figure 4. The experimental materials.

2.3 CGAN model

Conditional Generative Adversarial Networks (CGAN) are one of the variants of Generative Adversarial Networks (GAN). Consistent with the original GAN, the CGAN is mainly composed of two adversarial models: a generator responsible for generating pictures and a discriminator for judging the authenticity of the generated pictures. As shown in Figure 5, the main principle is:

(1) The generator generates a fake image based on the input image (Train A) and a random vector (Z). (2) The discriminator determines another set of corresponding pictures (Train B) and random vectors as true pictures. At the same time, it is discriminated with the fake pictures input by the generator, the real pictures are marked as 1, and the fake pictures are marked as 0. (3) If the generated image is judged to be false, the discriminator returns the deviation value between the fake image and the real image to the generator. It then upgrades the generator so that it can generate pictures that are closer to the real thing. On the contrary, if the discriminator judges that the generated image is real, the discriminator will continue to learn from the training set to improve the recognition ability. (4) Through adversarial training, the generator can finally generate fake and real pictures, so as to achieve the goal of generating building elevations.

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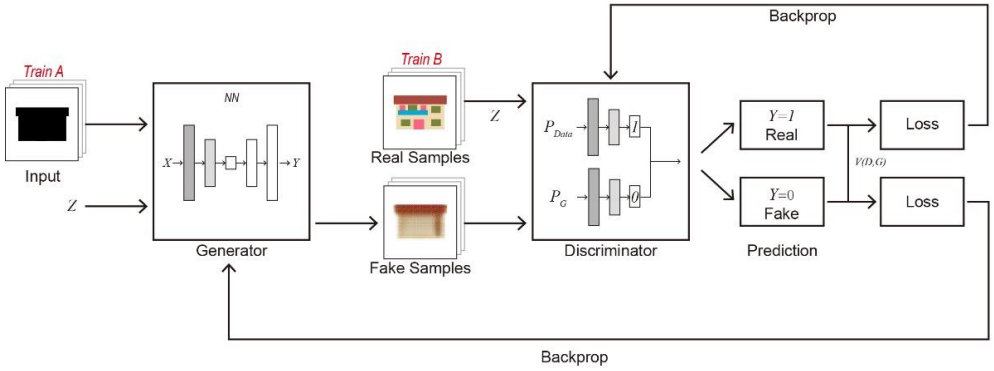
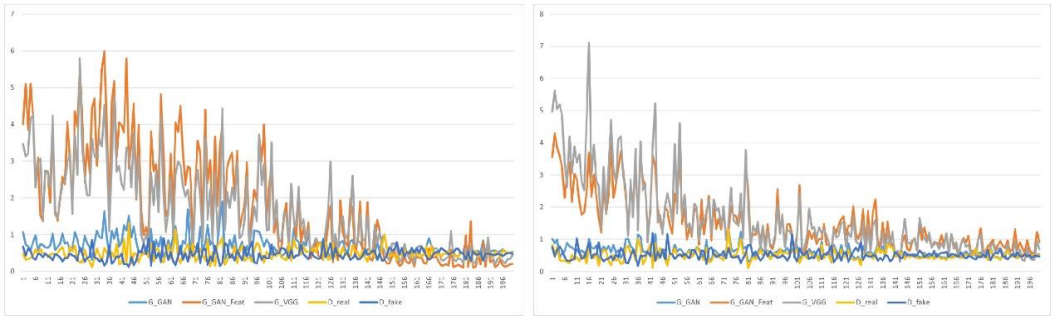


Figure 5. Principle of CGAN.

3. Results and Discussion

3.1 Training process

The Loss of the generator and discriminator of each generation in the model training process is counted to make a line graph (Figure 6). Model 1 represents the weight model, from BEP to FSL. Model 2 represents the weight model from FSL to BE. On the whole, after 200 generations of training, the Loss gradually decreased, and the fluctuation stabilized in a small range. This shows that the model is basically fitted and the training results are good. Comparatively speaking, the Loss fluctuation of Model 2 is smaller than that of Model 1, and the training is basically stable around the 80th generation. However, Model 1 still has significant fluctuations around the 130th generation, indicating that the training from Model 1 is more difficult and more complicated.



(1) Loss of Model 1 (2) Loss of Model 2

Figure 6. The loss value of the model.

The weight model of every 50 generations in the model training process is generated into pictures, and the result of the training process can be known (Figure 7). Overall, the images generated during the training process are almost identical to the real images, with high accuracy. In comparison, Model 1 is not as effective as Model 2, and in the results generated by the 100th generation of Model 1, the windows on the building facade have obvious errors. However, the 200th generation results are all up to the real level.

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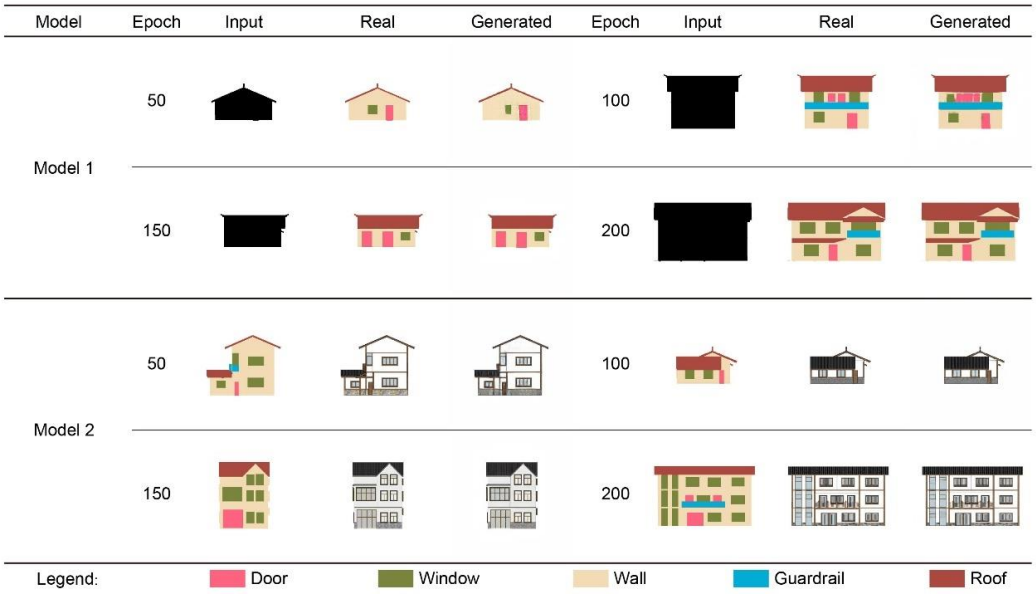

Figure 7. Model training process.

3.2 Model assessment

Randomly select 20% of the images (99 images) from all images (492 images) in the training set as the test set to test the trained model. As shown in Figure 8, numbers A to C are the test results of model 1, and numbers D to F are the test results of model 2. It can be seen that the generated results are relatively accurate, and the ideal results can be perfectly predicted with small errors. Among them, in the model model 2, the generated results can not only generate doors, windows, railings, roofs and other components according to the functional division of FSL. It is also possible to additionally generate facade style and decorative lines, reflecting the local style of the building.

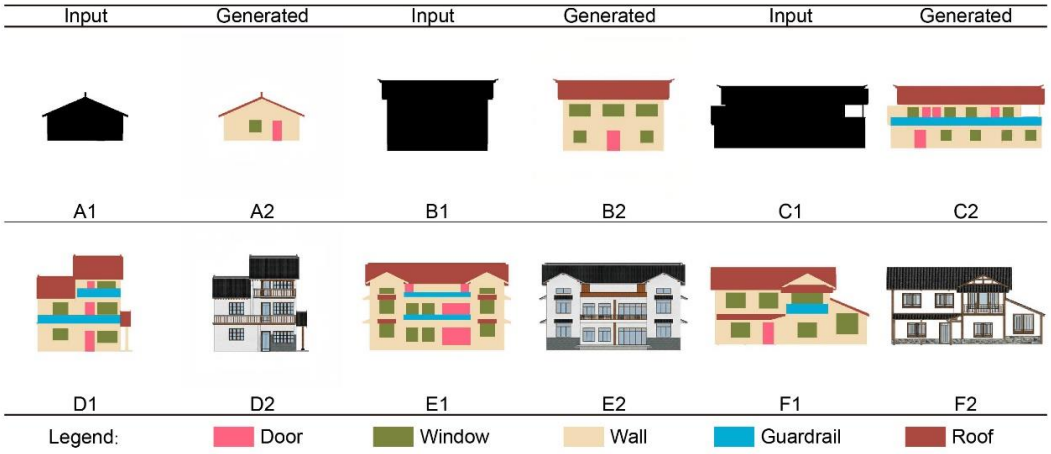

Figure 8. Model training process.

3.3 Model application

After the model training is completed, it can be applied to the project of village street style renovation. In the case of this study, the project has three main problems to be solved: (1) How to preserve the regional style in the design of the new building. (2) The problem of how to increase the facade design according to the opening of doors and windows for buildings lacking facade decoration. (3) How to restore unfinished buildings according to regional style. In addition, we propose that the model can be applied to some cultural products in villages and towns, such as road signs, house numbers, and souvenirs.

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3.3.1 Application in new building design

As shown in Figure 9, the feasibility of application in new architectural design is explored through the newly drawn 6 BEP samples. Figures A to C represent the impact of the building extension on the building's façade design. Figure D explores whether the machine can divide floors according to the height of the building. Figures E and F show some of the building outlines commonly found on the site. The above samples are generated using model 1. It can be seen from the overall generated results that the effect of the model generating FSL is general, and there are obvious errors. Except for the D2 image, the rest of the images have different degrees of offset. However, the position of each component of the building facade can be roughly judged, and further manual processing is required. In addition, it is also found that the machine can adjust the FSL correspondingly according to the change of the building control and the result has a certain reference value.

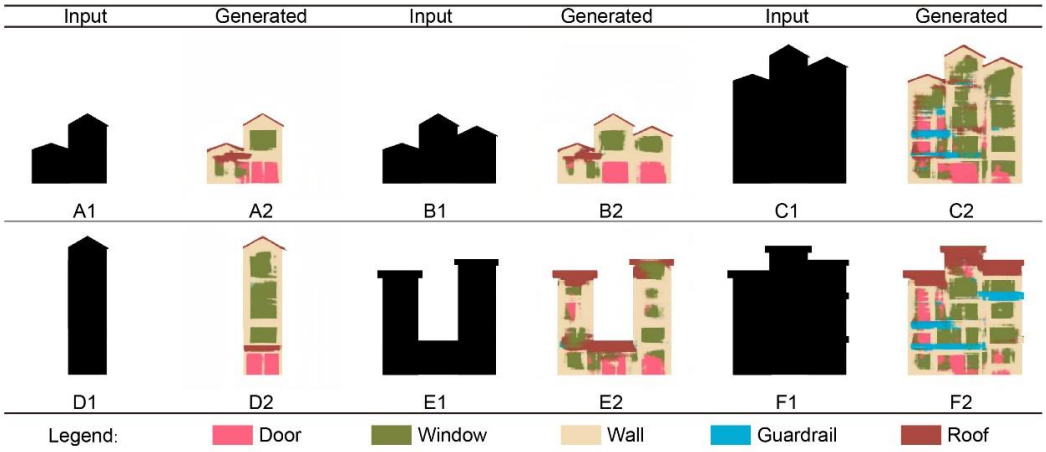

Figure 9. Assumed BEP generates FSL.

As shown in Figure 10, the results generated in Figure 9 are manually processed and then input into model2 for generation. Overall, the results are reasonable and there are no obvious errors. Specifically, the machine can adjust the final BE according to the size of each different function in the FSL.

(1) Automatically adjusting the style of the window. As shown in Figures 10(A1) and 10(A2), the machine can generate single-opening windows and triple-opening windows corresponding to different sizes of windows, and the three-opening windows are also equipped with shutters on both sides, which conforms to the characteristics of regional styles.

(2) Automatically adjusting the style of the door. In Figure 10 (A2) and (B2), it can also be seen that the machine generates single and double doors according to the different dimensions of the door. The materials of the doors generated by Figure 10 (B2) and (C2) are also significantly different. Figure 10 (B2) is a grid door, and Figure 10 (C2) is a wooden door.

(3) Automatically increase wall decoration. All the generated pictures can be seen, the generation of the wall is not only to give the white painted facade, but also to generate the line decoration of the plinth and the edge of the wall, which improves the aesthetics of the building facade.

(4) Automatically generate guardrails. As can be seen from the generated pictures with guardrails, although the color blocks of the guardrails are independent in FSL, the generated guardrail renderings are not isolated, but are fused to a certain extent according to the positions of doors and windows.

(5) Automatically adjusting the style of the roof. In Figure 10 (B2) and (E2), it can be seen that the machine generates pitched roofs with Howe-style truss decorations and dark tiled roofs for different roof shapes.

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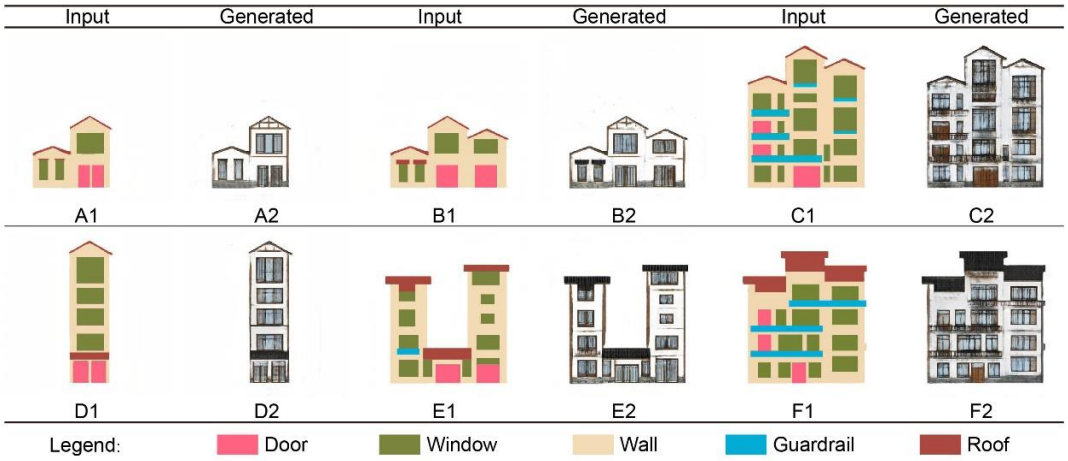

Figure 10. Processed FSL generates BE.

3.3.2 Building facade decoration

As shown in Figure 11, 6 main buildings on the site, such as Figure 11(A) to Figure 11(F), which lack facade decoration, were selected as materials for the test as an example. According to the openings of doors and windows on the facade of existing buildings, FSL is drawn manually and used as a sample for BE generation. Overall, the effect is good, the styles of each component are more reasonable, and there are no obvious mistakes. However, due to the influence of the existing building facade form and elements, if it is generated completely according to the status quo, the final effect is relatively common. Only turning the walls white and adding a small amount of facade decoration cannot fully reflect the regional style. In practical applications, in addition to directly generating the existing facades, it can be further artificially optimized to add more façade decorations to strengthen the embodiment of regional styles according to the economy.

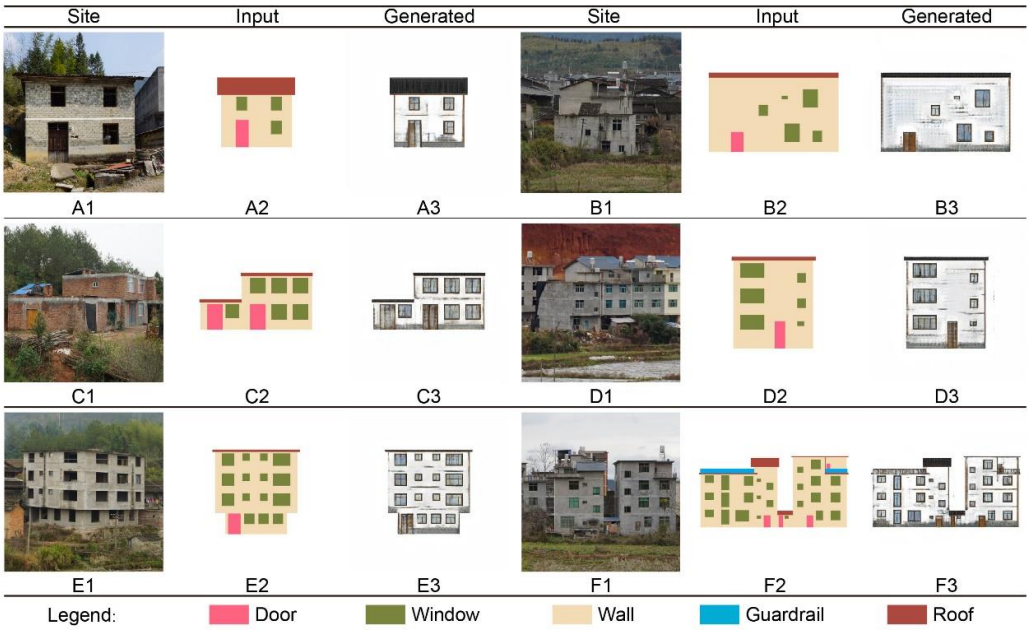

Figure 11. Application of model in facade decoration of village buildings.

3.3.3 Unfinished building restoration

During the on-site investigation, it was found that there are still some unfinished buildings on the site, with only floor slabs and frame structures, and lack of external walls. The generative design of the façade can be done according to the general outline of

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the building. As shown in Figure 12, after generation according to the above method, the generation effect is better on the facade with large volume and complex outline (Figure 12-B5). On the other hand, a facade with a smaller volume and a simple outline has a more general effect (Figure 12-A5). In the Fix-FSL step, the FSL with general effect can be manually adjusted, which is beneficial to generating the optimal BE.

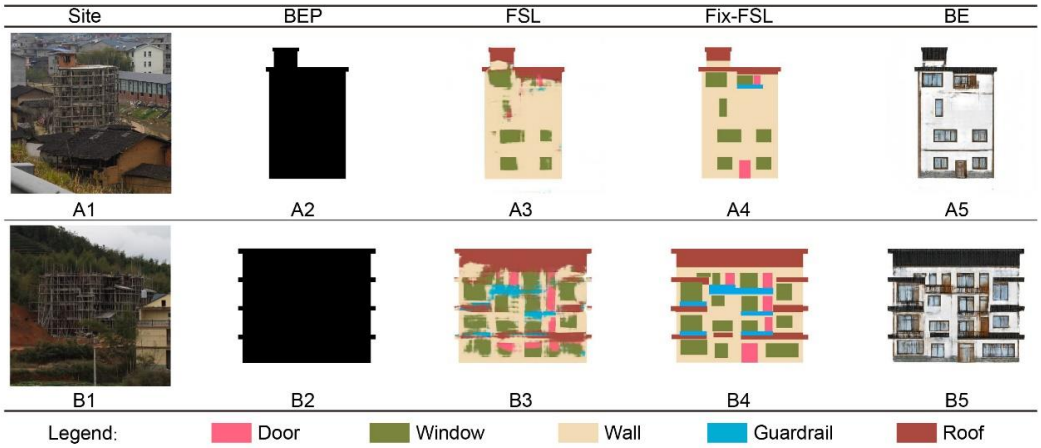

Figure 12. Application of Model in Facade Restoration of Village and Town Buildings.

3.3.4 Product Application

In addition to the application of the building itself, based on the future tourism planning of the village in this case, this study attempts to apply the model to the graphic design of the product as a reference for the design of tourism cultural products.

As shown in Figure 13, Figures A and B are common road signs and house numbers. After generating it twice as a material, the result is messy, and some text and icons are blurred. However, the overall style is consistent with the building, and some corrections and adjustments are required. Figures C and D correspond to the common tourist cultural products fans and water cups. After two generations, the final effect is quite impressive. Except for some stains, it can be used as a finished product almost directly. At the same time, the generation of Wuyi-style architectural styles in rural tourism products has also greatly promoted the promotion of Wuyishan World Heritage culture.

The tests of the above two types of products show that for road signs and house signs with strong readable functions, the effect of model generation is general. However, as a fan and a water cup with strong artistry, the effect of the model generation is better. Because the graphic design latitude of more artistic products is higher, the model can focus on further application of such products, which have significant value potential.

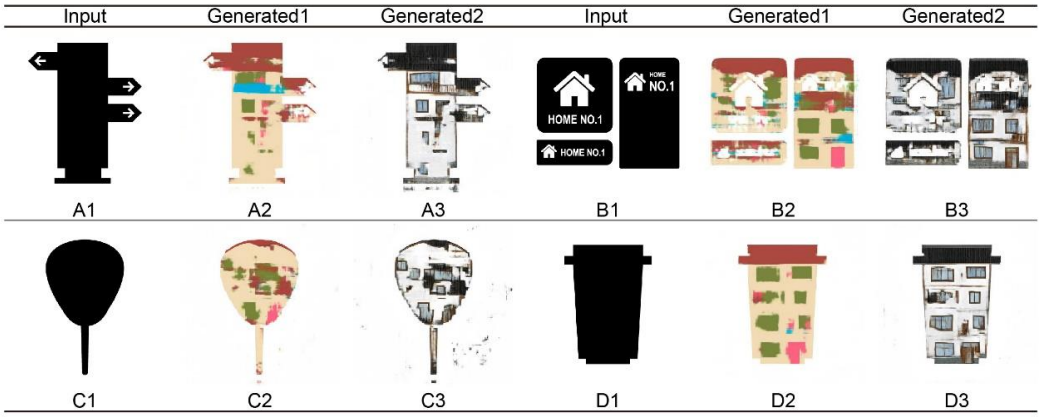

Figure 13. Application of the model in the product.

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4. Conclusions

With the development of the economy and the popularization of higher education, the style of villages, towns, streets and alleys and the quality of life of citizens have been paid more and more attention by citizens and governments at all levels. This study takes a village and town project in China as an example, builds a method of building facade generation in villages and towns based on the CGAN model, so as to gradually realize the governance of the style of villages and towns, and draw the following conclusions:

(1) This method has a significant efficiency advantage for the mass generation of hundreds of village buildings, and the generation effect is ideal. In addition, in addition to the generation of building facades, the product graphic design, especially the common tourist and cultural products fans and water cups, shows significant potential.

(2) In this study, the collected building facade pictures are subdivided into three types of pictures, BEP, FSL, and BE, as training materials. The combined application of Model 1 and model 2 can realize the ability to directly generate BE from BEP, which further expands the application scope of building facade generation in machine learning.

(3) In this study, limited by the number of samples or the CGAN model, the generated effect is still insufficient. In the future, we can continue to increase the samples of the training set, and specifically optimize the CGAN model to make up for the shortcomings of the experiment.

(4) This study takes traditional Chinese villages and towns as an example to thoroughly sort out the cultural value of the site. Extracting the Wuyi style under the influence of the "World Natural Heritage and Cultural Heritage List" as the target of style control has reference value in the value orientation of village style control. For urban and village projects with the same style of management and control needs, the research method in this paper can be applied and popularized. Combined with the method of machine learning CGAN model-assisted building facade design, it can inspire more application scenarios for architects and related practitioners, carry out interdisciplinary cooperation, and improve work efficiency.

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Appendix A

Machine learning environment configuration: the operating system is Windows 11 (X64), the Cuda version is 11.5, the deep learning framework is Pytorch, the graphics card is GeForce GTX 3070 (16G), and the processor is AMD Ryzen 9 5900HX (3.30 GHz).

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