GENERATIVE DESIGN METHOD OF BUILDING GROUP

Based on generative adversarial network and genetic algorithm

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Abstract. From parametric shape finding to digital shape generation, the discussion of generative design has never stopped in recent years. As an important watershed of building intelligence, generative design method has dual significance of scheme selection and building performance optimization in digital architectural design workflow. In this paper, the generative design method for the layout of residential buildings is studied. The pix2pix network, a kind of generative adversarial network, is used to learn the layout method of residential buildings in Shanghai. The generated layout uses Octopus, a genetic algorithm tool of Grasshopper, to generate the volume and optimize the sunshine hours and other performance parameters. In the generation process, different training sample sets and Pareto genetic algorithm optimization are used to realize the control of building density, plot ratio and height limit. This method can meet the real application scenarios in the early stage of architectural design to a certain extent, and has more expansibility, providing ideas for the generative design method of building group.

Keywords. Generative design method; generative adversarial network; genetic algorithm; sunshine optimization.

1. Introduction

As early as 1975, William Mitchell predicted the role and ability of computer in design in his book *Computer-Aided Architectural Design*(Mitchell, 1975). Nowadays, the development of computer technology and artificial intelligence has led to more expectations for computer aided architectural design (CAAD) in the field of architecture. From CAAD to the cyborg futures of man-machine symbiosis, such architectural design works are growing at a visible speed. It not only depends on the improvement of computer computing power and excellent performance and more intelligent algorithms, but also needs the transformation

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of architects' thinking paradigm. Generative design has been discussed for a long time. This design method combined with computer operation and algorithm optimization has great advantages in the diversity of generated schemes and the accuracy of building performance, which makes it gradually become a necessary step in architectural design, and gradually increases its proportion with the improvement of algorithm.

In 2014, the design work "Assignment of Ji Village" completed by students of School of Architecture in Southeast University, China, has applied multi-agent evolutionary model, which is an important exploration of generative design method(LI, GUO, & JI, 2015). On the basis of "quasi rectangular base dissection", the application of digital technology takes into account the deduction process of the scheme and the algorithm construction of objective constraints, and finally obtains the optimal combination of complex problems. SUN Chengyu of Tongji University applies a hierarchical parameter optimization system in the district planning of Beihai city in China(SUN, LUO, SONG, XIE, & RAO, 2017). By establishing the mathematical model of each control index and searching the multi solution space, the automatic generation of design scheme is realized. At the same time, the ventilation corridor evaluation is introduced to optimize the building layout repeatedly, which provides us with a generation idea of index constraint and performance optimization system. Liu Huijie uses multi-agent to study the sunshine constraint in the layout of residential buildings(LUI & JI, 2009). Through the establishment of mathematical model, the accumulated sunshine hours of buildings are optimized. As the pioneer of intelligent design under the background of big data and artificial intelligence, XKool tech explores the use of big data technology to quantitatively study(HE & YANG, 2018). The site value is quantified, and an algorithm model is designed to meet the architectural functional requirements. The convolutional neural network (CNN) is used to generate the optimal solution beyond the architect's ability. So far, there have been mature solutions to the technical problems of residential layout. Compared with the automatic generation method of building group layout, the method of single building form generation is difficult to quantify due to its morphological diversity. YUAN and LIN (2019) create a variety of mechanical torsion deformation building prototype. Combined with a small wind tunnel, the environmental performance-oriented form generation of single building is realized. Genetic algorithm and neural network are used in the optimization of architectural form, which is very enlightening.

Genetic algorithm (GA) is a complete set of theoretical methods proposed by Professor John Holland and his colleagues in the study of cellular automata in 1975(Holland, 1992). GA is a computational model to simulate the natural selection and genetic mechanism of Darwinian biological theory. It is a method to search the optimal solution by simulating the natural evolution process. As the most popular tool of generative design, GA has produced mature plug-ins or software tools for generative design in the past few years. Galapagos and Octopus of Rhino platform are both mainstream GA tools. Designers' use of this tools for scheme selection was once considered as the "standard answer" of generative design method. Many applications are focused on building layout automatic generation, building lighting, ventilation, and other fields.

GA and other traditional optimization algorithms such as Simulated Annealing algorithm, Particle Swarm Optimization algorithm and Pareto Front Optimization algorithm are mainly characterized by finding local optimal solution in limited solution space. The advantage of these methods is the high efficiency in a limited range, and the quality of the optimal solution will be guaranteed due to the controlled solution space, while its disadvantage is the lack of diversity of solutions. With the development of artificial intelligence technology, including machine learning and deep learning algorithm, some scholars turn to a generation algorithm which can create unknown form through a lot of known experience: Generative Adversarial Networks (GAN). Huang and Zheng (2018) use GAN to find the relationship between manually marked apartment plans and real drawings, and can output fuzzy floor plans after training. Mohammad (2019) uses GAN to generate building facade, which proves the possibility of the application of GAN in architectural design. Mokhtar et al. (2020) use GAN to learn the wind speed map, hoping to replace the traditional simulation software and realize the faster performance-based iterative generation method. Duering et al.(2020) propose an environment driven building group generation method combining GAN and GA. Ladybugs tools of Grasshopper are used to calculate the wind speed map(Duering, Chronis, & Koenig, 2020). It is clear that, GAN is used to guide GA to find the optimal solution of building group layout which provides a lot of inspiration for this paper.

2. Method

This study mainly relies on pix2pix GAN and octopus genetic algorithm tools to realize the volume generation of building under certain controllable indicators and environmental constraints. Firstly, the land and building data of Shanghai is collected, and then the data is cut by using the Geopandas package of Python, and two kinds of data sets for GAN training are constructed. The trained GAN model is used to predict the layout of a certain plot, and the prediction result is input into rhino platform, and the Octopus tool is used to generate the volume. The generated control indicators include height limit and plot ratio, and environmental constraints include the maximum sunshine hours calculated by Ladybug tools. The research workflow is shown in Fig.1.

2.1. DATA PREPARATION

The acquisition of data set is very important for the training of network. The quality of data set largely determines the accuracy and diversity of network prediction results. Before this research, the author has already had rich experience in the application of GAN and has been actively looking for network models suitable for architectural form generation among about 100 kinds of GANs, the collection of which is called as GAN Zoo. Conditional GAN seems to have great potential in the field of architecture, but the algorithm itself still does not support images and quantitative constraints both as the training conditions of the network.

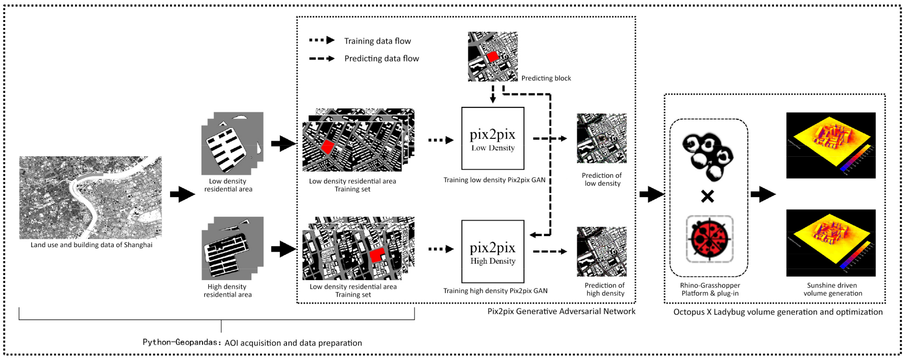


Figure 1. The research workflow.

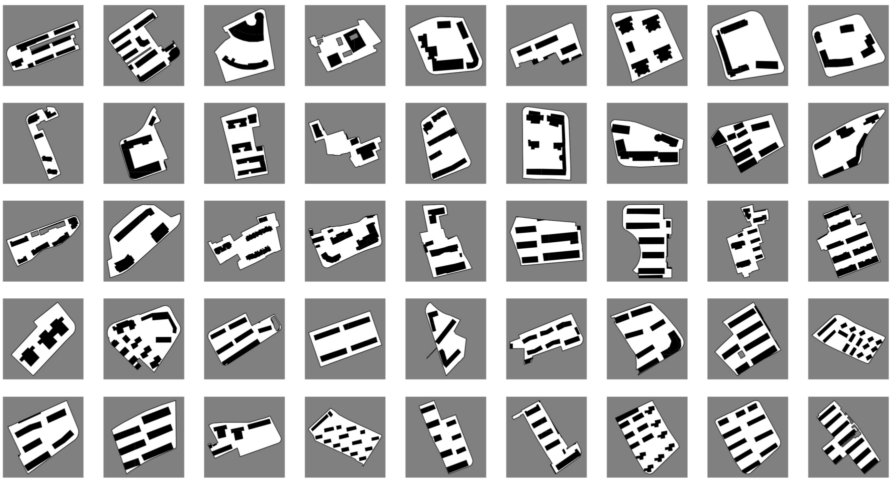


Figure 2. Low density residential layout dataset.

Facing the basic problem of building group generation, that is, the control of building density, plot ratio and other morphological indicators, we design two generation steps. In the GAN model, the network is trained by sorting out the data sets of buildings with different building densities, which can generate the layout of buildings with specified range of building density, while in the volume generation by using GA, the control of plot ratio is considered.

In this study, the building density of the building complex data set is mainly divided into two categories: low density (0.2-0.5) and high density (0.5-0.8) shown in Fig.2 & Fig.3. The Python development package Geopandas is used to cut the building and land use data in Shanghai, the area of interest (AOI) data of residential land is extracted and its building density is calculated and then classified.

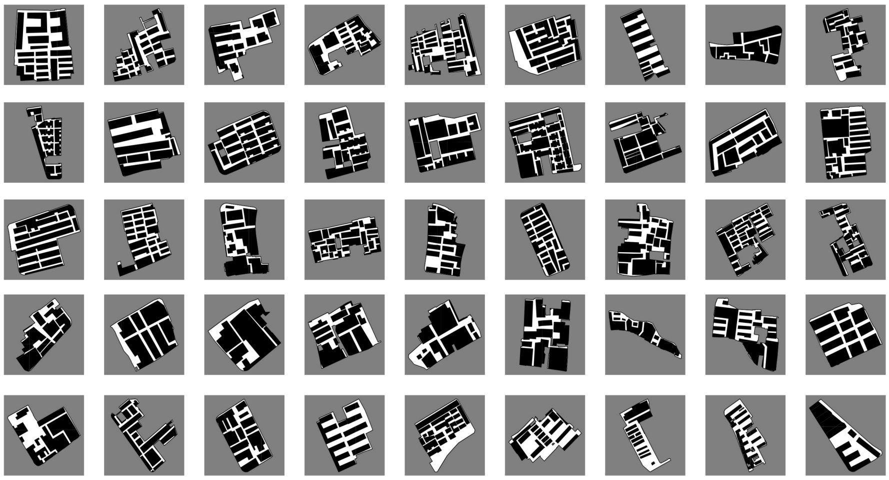


Figure 3. High density residential layout dataset.

The training set shown in Figure 1 is constructed for the two types of datasets. In the training set, each sample is composed of a labeled image (left) and an original image (right). The size of the image is 256 * 256, so as to meet the needs of GAN.

2.2. TRAINING PIX2PIX GAN

GAN involves a kind of unsupervised architecture as shown in Fig.4. It consists of two sets of independent networks, which are the targets of mutual confrontation. The first network is the classifier we need to train (D in the Fig.4) to distinguish whether it is real data or false data; The second networks is a generator (G in the Fig.4), which generates fake samples similar to real samples. The goal of generator G is to draw a fake image that is very close to the real image to cheat D. the method is to select the elements in the potential space of training data and add random noise. In the training process, D will receive the true data and the false data generated by G. its task is to determine whether the image belongs to the true data or the false data. In order to train a good generator, we need to tune the parameters of both sides at the same time. If D is correct, the parameter of G should be adjusted to make the false data more realistic; while if D is wrong, it is necessary to adjust the parameters of D to avoid the next similar judgment error. Training will continue until the two enter a state of balance. Through continuous training of classifier D and generator G, the generated images gradually highly resemble real images.

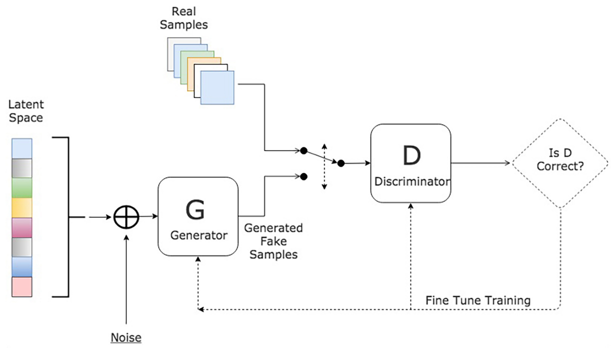


Figure 4. Algorithm principle of GAN.

Pix2pix, as a conditional GAN, can learn a conditional generation model, that is, the corresponding relationship between input image and output image(Isola, Zhu, Zhou, & Efros, 2017). In this paper, the input image is the label image whose target area is erased by red color block, and the output image is the generated building layout.

2.3. OPTIMIZATION BY OCTOPUS GA TOOLS

Different from Galapagos, octopus is a multi-objective optimization algorithm based on grasshopper platform. It is developed by Vienna University of Applied Arts in Austria and Bollinger + Grohmann engineering firm in Germany. It combines Pareto optimal principle and GA. For multi-objective optimization problems, the software provides user-defined optimization parameter options. At the same time, octopus provides rich interactive operation methods and convenient data storage and transmission functions. Compared with Galapagos, octopus not only can deal with multi-objective optimization calculation, but also has a higher degree of visualization. The solution process and many optimization feasible solutions are presented in 3D interface, in which designers can screen the results. In short, octopus provides architects with a simple and easy to learn multi-objective optimization tool and brings many possibilities for design work.

In this study, a series of constraints are set for the volume generation using the building layout generated by GAN including height limit, plot ratio and maximum sunshine hours. The maximum height of the building group is less than the height of the surrounding highest building after adding or reducing three floors, so as to ensure the transition of urban facade, as well as the generated results are as reasonable as possible when the specific height limit value is unknown. The three plot ratio ranges are 0.8-1.2; 1.5-2.0; 2.0-2.5. It is hoped to generate as rich and controlled volume as possible under the same building layout by setting different plot ratios. Maximum sunshine hours is calculated by Ladybug sunshine calculator shown in the Fig.5, Fig.6 shows more details of the link of the battery.

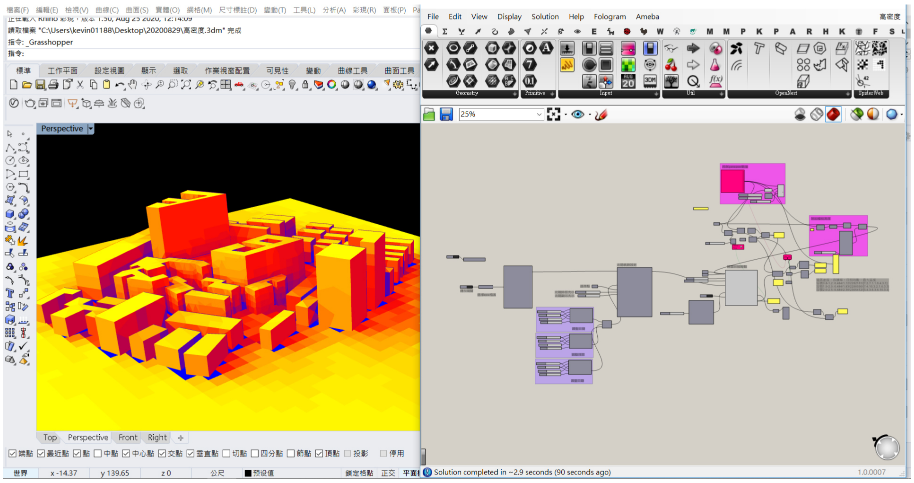


Figure 5. Ladybug sunshine calculator visual interface.

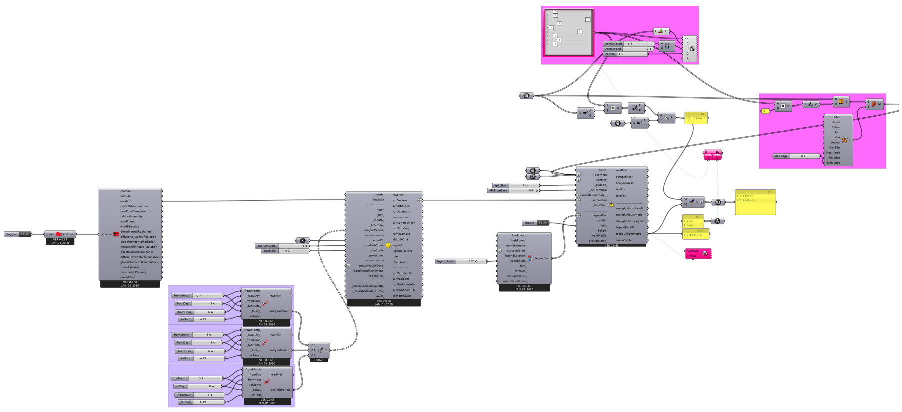


Figure 6. Details of the link of the battery.

3. Results and Discussion

3.1. GENERATION RESULTS OF PIX2PIX GAN

The results of pix2pix generation are shown in Fig.7. It can be seen that the generation results of label images in low density and high density models show certain regularity. In the result of low density generation, the buildings respond effectively to the boundary of the site and leave public space in the center. It reflects the advanced nature of the network algorithm, not only learning the layout of the building group, but also learning the relationship between the building group and the site. The building density of the result is 0.377, which meets the requirement of low density generation.

In the high density generation results, it shows that the consideration of the network for high density layout is not only in line with the local texture, but also learns the surrounding E-shaped and C-shaped architectural forms and integrates them into the generation scheme, which makes the scheme more specific with local characteristics. The building density of the result is 0.684, which meets the requirement of high density. Considering that GAN is an algorithm to generate bitmap, so the computer can not understand the content of the image, and can only generate the required pixel distribution, which makes the generated results have a certain degree of ambiguity, and add more image noise. But even so, the above generated results can provide architects with the analysis and inspiration of the preliminary general plan of the scheme and will further enter the Octopus tool for volume generation.

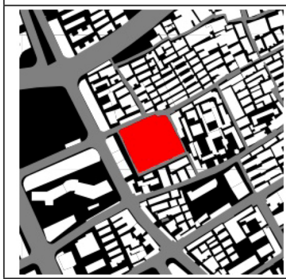
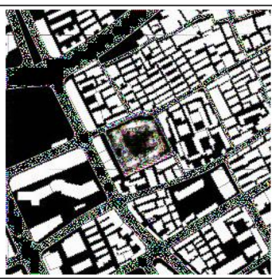
Labeled Image	**Result of Low Density**	**Result of High Density**
		
	Building Density：0.377	Building Density：0.684

Figure 7. The generation results of pix2pix .

3.2. GENERATION RESULTS OF OCTOPUS

The generation results of Octopus are shown in Fig.8. The result is very interesting, and it is very close to the design of a real designer. We have generated the volume of low density and high density layout, and listed the scheme with the largest sunshine hours in the range of three plot ratios. Apparently, the height of the generated building is relatively uniform, which is due to the height constraint of the generation process. Because Octopus directly operates the Rhino model, the generated results can be directly connected to the architect's design workflow, so it has strong practicability.

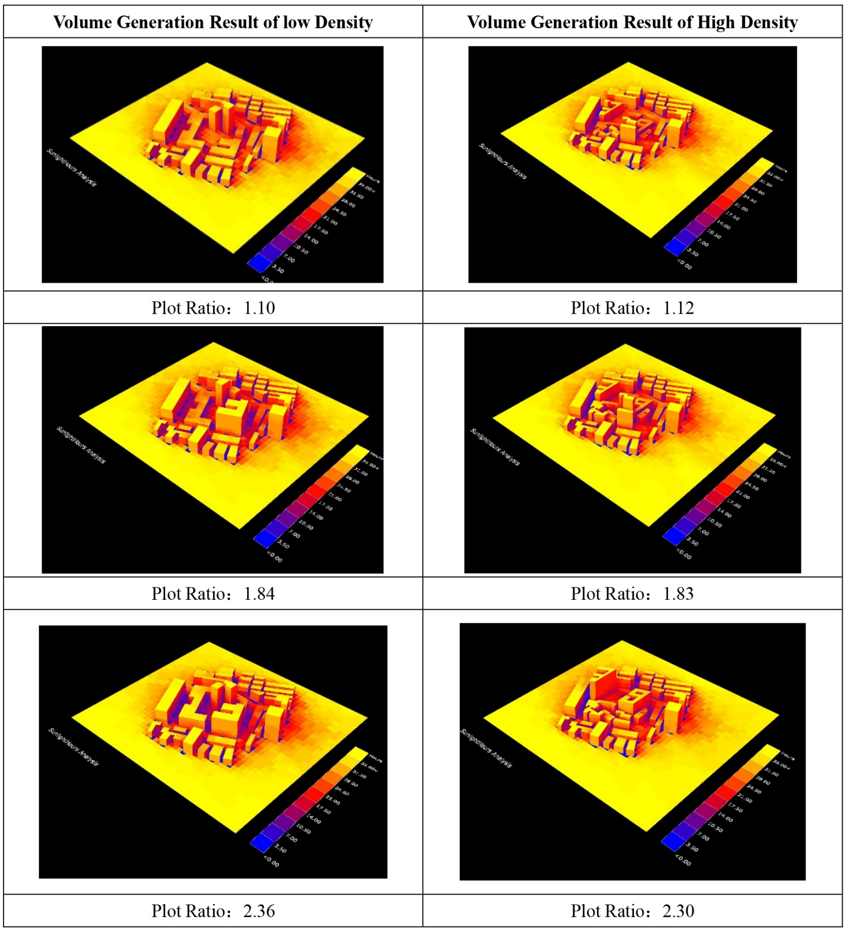


Figure 8. The Generation Results of Octopus.

4. Conclusions

The combination of Generative Adversarial Network and Genetic Algorithm of traditional generative design algorithm not only expands the diversity of genetic algorithm, but also makes up for the instability of the generation form of GAN. This exploration is of great significance to the development of generative design method. The consideration of performance optimization in this study is feasible. At present, the generation of GAN needs to be further optimized. For example, in the high density layout generation, it is obvious that the generated results are against the architect’s rationality, which is the plan is too complex. The future effort should be put in the preparation process of the dataset. More quality plans need to be prepared for network training. Meanwhile, in the future, more environmental parameters could be added to Octopus multi-objective optimization to control the generation of building form including wind environment, light environment, energy consumption, carbon emissions, etc., to truly achieve performance-oriented form generation.

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