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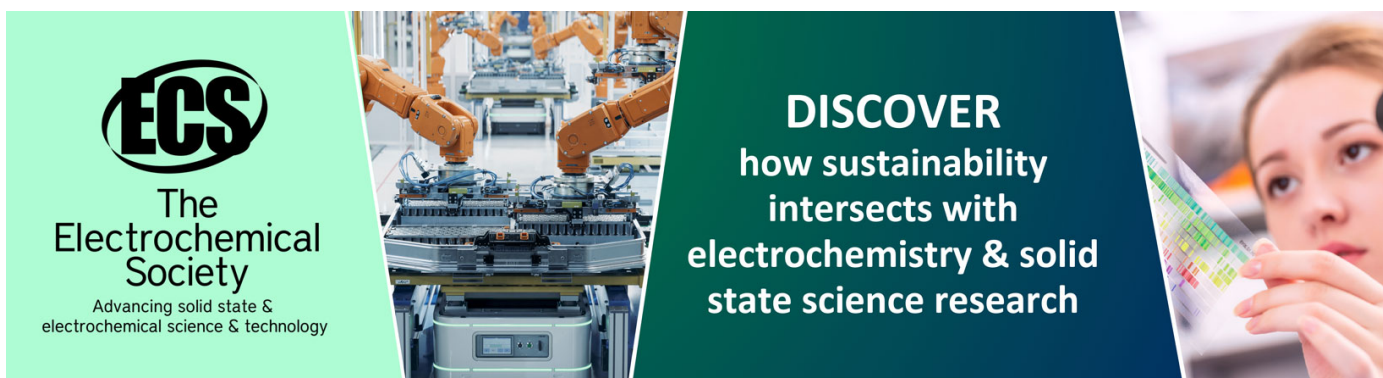
## Generating Residential Layout Based on AI in the View of Wind Environment

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## Generating Residential Layout Based on AI in the View of Wind Environment

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**Abstract.** There is a contradiction between the high-density residential area development form and comfortable outdoor physical environment. The existing studies on wind environment of high-rise residential areas only provide the guidance for the simple general layouts, which cannot cope with the fact that most high-rise residential areas are mixed of point buildings and board buildings, and it would cost a lot of time and resources to carry out computer simulation of each layout. This paper presents a new tool, which uses the automatic optimization function of genetic algorithm and the prediction function of fully convolutional neural network to integrates three functions: the automatic generation of high-rise residential layout, the simulation of wind environment and the comparison for optimization, to learn plan scheduling and obtain the optimal solution for high-rise residential layout under specific plot ratio and plot conditions, provides guidance for today's fast-paced architectural design.

### 1. Introduction

With the rapid expansion of the city and the explosive growth of the high-rise buildings, the phenomenon of urban quiet wind has increased, which result in a significant decline in air quality. At the same time, with the improvement of people's environmental awareness, residents have gradually realized the importance of the outdoor physical environment. Therefore, it is very necessary to carry out research and simulation of wind environment during the layout design stage of the community.

With the rapid development of computer simulation technology, Computational Fluid Dynamics (CFD) software such as FLUENT and PHOENICS have been widely used in the study of architectural wind environment due to their reliability and comprehensive performance. In the research on the wind environment of residential area, Littlefair et al. [1] studied the different effects of different layout forms of residential areas on the wind environment, and proposed environmental optimization schemes that reasonably influence the wind environment according to different layout forms. Kan Qi et al. [2] used PHOENICS to optimize the outdoor wind environment of high-rise buildings by changing the building orientation. Shan Qiya et al. [4] used the ENVI-met software to simulate and analyze the influence of determinant, peripheral and mixed building layouts on the wind environment in severe cold areas based on the climate conditions in Harbin. Zhang Shengwu [7] simulated the influence of different architectural design elements on the wind environment through PHOENICS, and analyzed three residential areas in Hangzhou, came up with suggestions for optimizing the wind environment in residential areas in Hangzhou. In general, the current research on wind environment of high-rise residential areas mainly focuses on changing the orientation of individual buildings, adjusting the spacing between buildings, studying the relationship between the plan



layout and the wind environment, and optimizing the layout of residential areas in specific cities. No team has studied the generation method of the complex unequal height point-board hybrid layout from the perspective of wind environment, which is inconsistent with the situation of different heights and different sizes of individual buildings in high-rise residential areas in real life.

Wind environment optimization is a complicated process, the above computer simulation software only has a single simulation function, which results in: ① The simulation time is long. The single simulation takes 20 to 30 minutes, and multiple simulations are needed when there are many schemes. ② The above software only provides the simulation function, so the optimization of the scheme depends on the personal experience of the designer.

In order to solve the problem of automatic optimization of high-rise buildings, Liu Yupeng, Yu Gang et al. [8-9] proposed a Grasshopper-based parametric platform--an automatic optimization method for improving the urban microclimate by adjusting the urban form. However, the platform only carried out experiments on the winter weather conditions in a cold city--Shenyang, and the building scale was relatively rough, it was impossible to simulate and optimize smaller-scale residential buildings.

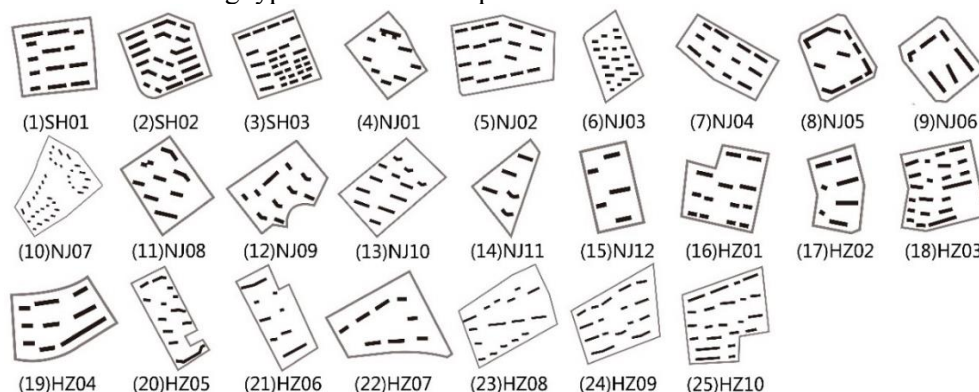
Aiming at the problem of automatic generation of high-rise residential layout from the perspective of wind environment, this paper proposes a new calculation software-"automatic generation and comparison software for high-rise residential layout based on rapid prediction of wind environment", which provides an automatic generation and comparison method for the layout of high-rise residential areas in the Yangtze River Delta, to improve the work efficiency and design accuracy of architects in the early design stage.

## 2. Methodology

Firstly, summarize the commonly used building sizes and layout types of high-rise residential buildings in the Yangtze River Delta, and generate a high-rise building layout model library. Secondly, use PHOENICS to simulate the wind environment of the model library. Then use genetic algorithms and machine learning algorithms to find the relationship between the layout and the factors affecting the wind environment. Finally, a new calculation software was written, which integrates three modules of automatic layout generation, wind environment simulation and comparison to obtain the optimal layout of high-rise residential buildings under specific plot ratio and plot conditions.

### 2.1. Creation of training database

**2.1.1. Building model database.** This research selects 25 residential areas in the Yangtze River Delta (as shown in Figure 1) as the research samples to investigate its plot size, floor area ratio, building size and height data. The building types used in the experiment are shown in Table 1.



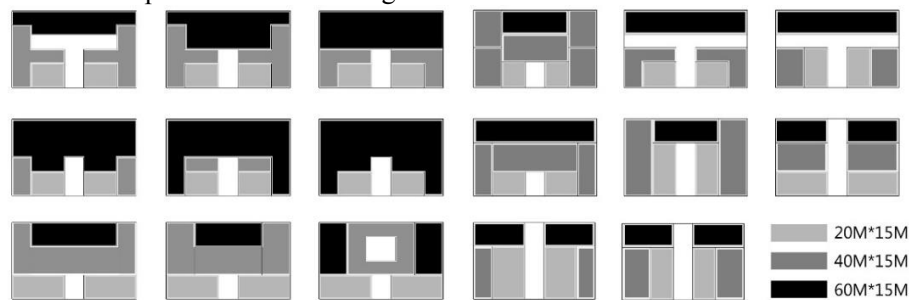
**Figure 1.** Plans of sample residential areas.

**Table 1.** Adopted building types.

| Building type | Number | Plane size | Number of layers |
|---------------|--------|------------|------------------|
| Slab block    | B1     | 60m*15m    | 11F              |
|               | B2     | 40m*15m    | 18F              |
|               | B3     | 60m*15m    |                  |

|             |    |         |     |
|-------------|----|---------|-----|
| Point block | B4 | 40m*15m | 30F |
|             | B5 | 60m*15m |     |
|             | P1 | 20m*15m | 11F |
|             | P2 | 20m*15m | 18F |
|             | P3 | 20m*15m | 30F |

The scale of the experimental land selected in this paper is 390m\*240m, and the plot ratio is controlled at 2.6~2.65. In order to avoid the disorderly arrangement of buildings of different heights and sizes, this research divides the land into "green spaces", "roads", and "contour buildings" to control the layout of the buildings and make the layout automatically generated by the computer more in line with the actual situation. The plan for the cluster division of point-board mixed high-rise residential area is as follows:

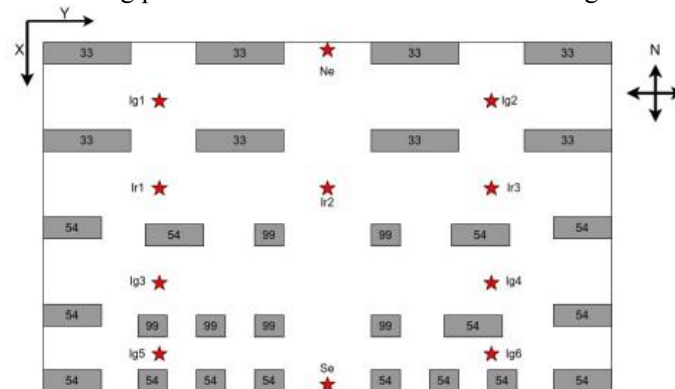


**Figure 2.** Group division plan of point-board mixed high-rise residential area.

The distance between buildings is controlled by "The code for fire protection design of buildings GB50016-2018" and T-Arch software sunshine simulation. The research only selects two point-type houses and two board-type houses in each plan, and the board-type houses are placed in a southerly direction. Finally, 179 combinations of plot ratios and 880 layouts were obtained, which served as the building model database of this research.

**2.1.2. Wind environment simulation database.** This study investigated the wind environment data of three typical cities in the Yangtze River Delta -Shanghai, Nanjing, and Hangzhou. The experimental wind speed used was 3m/s, use south wind (summer) and north wind (winter). (Data source: China Meteorological Administration daily value data and cumulative annual value data, China Meteorological Data Network: <http://data.cma.cn>.)

Use PHOENICS to simulate the wind environment of the building model database obtained above. Regardless of other buildings around the plot, set the size of the simulation area to 3 times the size of the plot in the XYZ direction (1170m\*720m\*270m). After the simulation, the wind environment data at the pedestrian height of 1.5m for each plan is derived. In order to facilitate the analysis of the experimental effects of the prediction model, this paper selects 11 locations with frequent activities of residents in the layout as wind speed measurement points: the entrance and exit of the community, the center of the road in the community, the center of the building cluster and the center of the green space at a height of 1.5m. These specific locations of the measuring points are shown as the star marks in Figure 3.



**Figure 3.** Locations of measurement points.

After the above process, the training database of this research is obtained, including the building model database and the wind environment simulation result database.

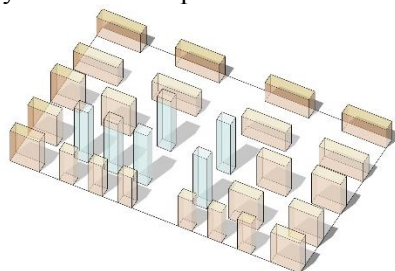
**2.1.3. Data processing.** On the plane problem, the matrix has good expressive ability, it can save the position information and the value at that position. Therefore, this research uses 5m\*5m as a cell to divide the experimental land into a matrix of 48\*78 units. Enter the height of the building here in the grid. The height of the open space is recorded as 0. The dimensions of the building represented by a matrix are shown in Table 2.

**Table 2.** Building types in matrix representation.

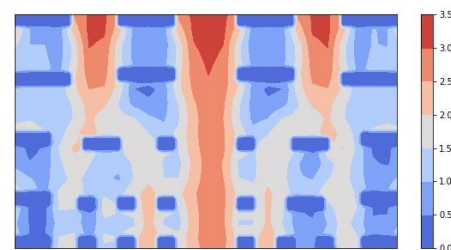
| Building type | Number | Unit length | Unit width | Height(m) |
|---------------|--------|-------------|------------|-----------|
| Slab block    | B1     | 12          | 3          | 33        |
|               | B2     | 8           | 3          | 54        |
|               | B3     | 12          | 3          | 54        |
|               | B4     | 8           | 3          | 90        |
|               | B5     | 12          | 3          | 90        |
| Point block   | P1     | 4           | 3          | 33        |
|               | P2     | 4           | 3          | 54        |
|               | P3     | 4           | 3          | 90        |

There are as many as 60,000 original wind speed data points for each scheme, and the difference between adjacent data is very small. Therefore, this research divides the wind speed data into 5m\*5m cells, and uses the average wind speed value inside the cell to represent the wind speed.

So far, this research has obtained the processed building model database and wind environment simulation result database. The database is divided into training set and test set at a ratio of 7:3. Figure 4 and 5 show the building layout and wind speed distribution diagram of a scheme.



**Figure 4.** Layout of buildings.



**Figure 5.** Wind velocity profile.

## 2.2. Experimental process.

**2.2.1. Layout optimization.** This research selects genetic algorithm in the layout optimization stage. The genetic algorithm starts from a set of randomly generated initial individuals, through the three processes of selection, crossover and mutation, to produce a new generation of higher-quality individuals; then selects individuals according to the individual fitness to enter the next round of iteration, to improve the quality of the population. After repeating this iterative process many times, the optimal solution is continuously approached.

In the layout optimization problem, genetic algorithm can be used to effectively constrain the layout plan. Traditional genetic algorithms use binary or integer coding methods to encode individuals, but both types of coding methods are linear. The problem studied in this article is a two-dimensional plane problem. Therefore, this research improves the traditional genetic algorithm and uses matrix to represent different individuals, that is, divides the layout with a uniform grid to form a large matrix.

After the architect enters the building type, building quantity and building layout, different buildings will be randomly placed within the land area according to the group division plan to ensure that all buildings can be placed in the layout and will not appear overlapping situations. A total of 50 different initial layouts were randomly generated in the experiment, which will be used in the subsequent optimization process.



This research is based on the premise of saving land, using the minimum distance between adjacent buildings as the optimization goal, the following formulas are used when calculating the layout adaptability:

$$Penalty = \sum \frac{dis_{\min}^d}{dis_{truth}^d + 1} \quad (1)$$

$$Fitness = \frac{1}{\sum_i^{N_b} Penalty + 1} \quad (2)$$

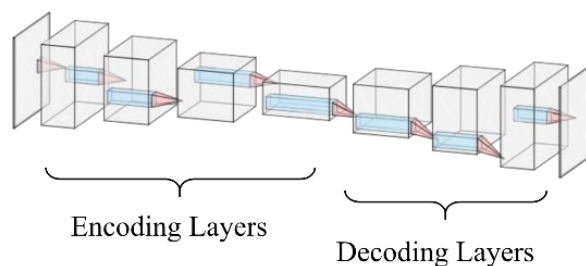
Among them,  $d$  represents the direction, there are four directions: east, west, south and north;  $dis_{truth}^d$  represents the true distance in the  $d$  direction;  $dis_{\min}^d$  represents the minimum distance in the  $d$  direction. Calculate the ratio of the minimum distance and the real distance in the four directions as the penalty value, and the reciprocal is the fitness of a building, the fitness of the entire layout is the sum of the fitness of all  $N$  buildings. The fitness formula shows: the closer the actual distance and the minimum distance are, the higher the fitness will be. When the adaptability of the layout is smaller, the possibility of being eliminated is greater. The eliminated layout will no longer participate in the next round of optimization, which ensures that the algorithm is updated in the direction of the optimal solution.

After multiple iterations, the fitness of the layout tends to a stable value, and the layout corresponding to the fitness is the optimal solution. In this study, the fitness threshold is taken as 100. If the worst fitness of a new generation layout reaches 100, the optimization process will stop. The layouts generated in this article are sorted from high to low according to the degree of fitness to obtain the optimized layout library.

**2.2.2. Wind speed prediction.** Convolutional Neural Networks (CNN) automatically extract features on images by constructing multi-convolutional layers. At present, CNN has been widely used in the field of image classification and image detection. Unlike traditional CNN, Fully Convolutional Neural Networks (FCN) can accept input images of any size, and use the deconvolution layer to up-sample the feature map of the last convolution layer to restore it to the same size as the input image, which generates a prediction for each pixel.

In this study, the FCN model is selected as the proxy model to realize the functions of CFD software, and the simulation time is shortened as much as possible under the condition of allowing certain errors, and the wind speed prediction of the optimized layout library is quickly carried out.

The structure of the network we use is shown in Figure 6. This model has 9 convolutional layers and can be divided into two parts: encoding layers and decoding layers. In encoding layers, the model takes images as input and extracts the structural features of layout planes through four convolutional layers.



**Figure 6.** The network structure of CFD agent model based on FCN.

After the wind speed data of the building layout is predicted, it needs to be filtered from the perspective of wind environment. This study uses the wind speed ratio <sup>[12]</sup> to evaluate wind environment comfort (wind speed ratio = wind speed at the measuring point/initial wind speed). When the wind speed ratio is greater than 2.0, residents will feel that the wind is too strong, and even safety problems may occur; When it is less than 0.5, there will be a quiet wind zone of the site, which is not conducive to air flow <sup>[13]</sup>. Therefore, the selection process based on wind environment comfort in this paper is divided into two steps: ① Eliminate the layout with wind speed ratio greater than 2.0 measurement points; ② Since each layout have points with wind speed ratio less than 0.5, this study counted the area where the wind speed ratio is less than 0.5 and display the number on the software interface.

Through the layout optimization and wind speed prediction process above, a software for automatic generation and comparison of residential layout based on rapid prediction of wind environment is compiled. It is based on the PyQt framework, and mainly used for the layout design of high-rise residential buildings. It provides a reference for architects in the selection phase of the layout. The main functions are: automatic generation of residential layout, rapid simulation of wind environment performance and comparison for optimization.

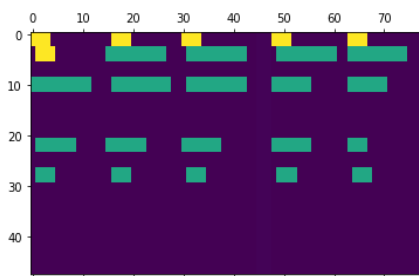
### 3. Result analysis

#### 3.1. Analysis of layout optimization effect

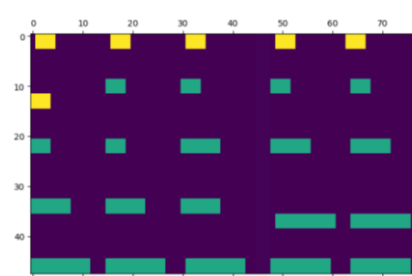
This paper selects a sample model to analyze the optimization effect of genetic algorithm. Table 3 shows the building parameters selected in an experiment, and Figure 7 and 8 show the layout before and after optimization.

**Table 3.** Buildings used in the experiment.

| Wind direction | Building type | Number | Quantity |
|----------------|---------------|--------|----------|
| North          | Slab block    | B1     | 0        |
|                |               | B2     | 6        |
|                |               | B3     | 7        |
|                |               | B4     | 0        |
|                |               | B5     | 0        |
|                | Point block   | P1     | 0        |
|                |               | P2     | 6        |
|                |               | P3     | 6        |



**Figure 7.** Layout before optimization.



**Figure 8.** Layout after optimization.

It can be seen from the figure: ①Due to the crossover process of genetic algorithm, the relative position of some buildings has changed after optimization; ②Due to the mutation process of genetic algorithm, the position of some buildings has slightly shifted.

On the whole, the optimized building layout is more in line with actual architectural design requirements: the sunshine spacing has been met, and the land utilization rate has also been improved.

#### 3.2. Analysis of wind speed prediction effect

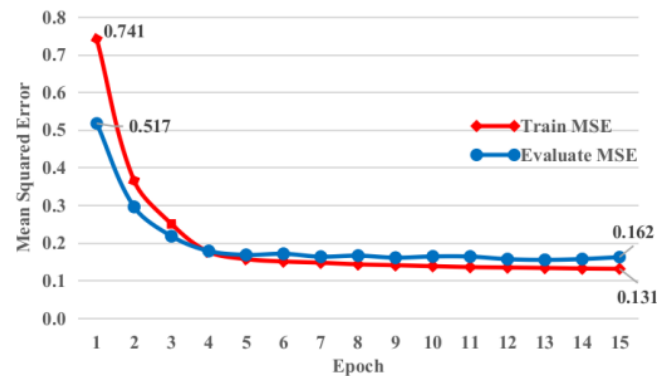
This research uses mean-square error (MSE) as an evaluation index to evaluate the error between the wind speeds simulated by PHOENICS and predicted by FCN model. The calculation formula of the mean-square error is:

$$MSE = \frac{1}{n} \sum_{i=1}^n (y_{truth} - y_{predict})^2 \quad (3)$$

Where  $n$  is the amount of sample data, which means the number of cells in a layout.  $y_{truth}$  is the wind speed value simulated by PHOENICS,  $y_{predict}$  is the wind speed value predicted by FCN. The smaller the MSE value, the higher the accuracy of the prediction model.

The change trend of the MSE value during model training process is shown in Figure 9. It can be seen from the figure that the training error of the model shows a downward trend, and the downward

trend in the first 6 rounds is relatively rapid. As the robustness of the model increases, the downward trend of the MSE slows down, and the MSE basically remains unchanged after the 12th round, which indicates that the training effect of the model has reached the optimal level. After 15 rounds of training, the MSE of the model on the training set reached about 0.13, and the error on the test set reached about 0.16.



**Figure 9.** Change trend of MSE during the model training.

The analysis shows that under the test error of 0.16, the average wind speed error is about 0.5m/s, while the actual wind speed range is about 0 to 4m/s. From the feeling perspective of the human body, the error is acceptable.

This paper compares the time efficiency of PHOENICS simulation and FCN prediction, as shown in Table 4. It can be seen that although the training process of the model takes 1 hour, it only takes a few seconds to predict the wind environment of a layout. Compared with the simulation using PHOENICS, the time efficiency is obviously improved, the software has achieved the expected effect.

**Table 4.** Comparison of time efficiency between software simulation and model prediction.

| Method    | Training Time (h) | Evaluate Time per layout (s) |
|-----------|-------------------|------------------------------|
| PHOENICS  | -                 | 600 ~ 1200                   |
| FCN Model | ≈ 1.0             | ≈ 1.07                       |

#### 4. Summary

Based on the investigation and summary of the prototype of high-rise residential buildings in the Yangtze River Delta, this research uses the optimization function of genetic algorithm to optimize the layout of the building group based on the minimum distance between buildings, and uses the FCN model to predict the wind environment of the layout, and then combine the two algorithms to screen out the layout plan that meets the requirements. Finally, a software for automatic generation and comparison of residential layout based on rapid prediction of wind environment is compiled. After error analysis and time efficiency comparison with traditional simulation methods, the wind speed data error generated by this method is controlled within a meaningful range, and the time efficiency is significantly improved.

But this article still has certain limitations. The cases and data used in this article come from actual cases in the Yangtze River Delta, but the plot size, plot ratio, and wind speed used in the study are preset data, which fail to provide a universally applicable high-rise residential automatic generation program and wind environment simulation. The research is cooperating with the design institute currently to improve the universality of the method through simulation error analysis of more actual cases. Therefore, in the follow-up research, the supplementary database of "plot size, plot shape, plot ratio, wind speed, wind direction" will be gradually added.

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