A GENETIC ALGORITHM APPROACH TO OPTIMIZING THE DISTRIBUTION OF BUILDINGS IN URBAN GREEN SPACE

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Abstract. Certain buildings are required in urban green space according to the Chinese regulations, and their area depends on the type and area of the green space. The scale of the single building or the disperse extent of the building group dramatically influences the local ecological environment and landscape. However, it is lack of effective methods to evaluate the distribution of buildings, and it is hard to plan and manage the buildings in the green space. According to the description of distribution features of geographic objects in geostatistics, this study presents the Index of Distribution (IOD) to describe the distribution pattern of buildings in the green space. Yuhuatai Park and Qingliangshan Park of Nanjing are chosen as cases to verify the effectiveness of IOD. Based on the genetic algorithm, the paper also presents a generating model, which can generate the plan of the buildings corresponding with the specific IOD. The model is effective to respond with the flexibility of location of the building. The results of the model can be used as the valuable reference to the planning of buildings in the green space.

Keywords. Genetic algorithm; index of distribution; green space.

1. Introduction

Urban green spaces usually “supply residents with green environments and good outdoor recreation sites”, and “provide a certain recreational and service facilities” (Standard for Classification of Urban Green Space, China). These facilities can be specifically shown as various kinds of buildings for rest, sightseeing, service, public and management. The buildings in the green
spaces undoubtedly bring a certain impact on the partial ecological environment and human landscape of the green space. The building form itself is one of the four major factors that influence microclimate (Gaitani et al. 2007), and its scale, volume and distribution state will influence the temperature of the surrounding environment and the partial ecological effect (Martins et al. 2012).

However, in the current national regulations, although detailed provisions are enacted for the buildings area and height within the green space, there are no corresponding regulations on the distribution of buildings. When the area of the green space is very large, the site area of buildings will reach a larger scale. Such large-scale buildings within the green space will play a tremendous negative effect on the partial ecological environment and cultural landscape.

In order to avoid large-scale building or clustering within the green space, the quantitative evaluation index is a principal requirement. Based on such index, the government could evaluate and control the layout planning and construction of buildings within urban green spaces. Moreover, the planners and architects could use it as reference standard to design the buildings layout.

According to the description of distribution features of geographic objects in geostatistics, this study presents the Index of Distribution (IOD) to describe the distribution pattern of buildings in the green space. Then the study targets the buildings layout plan that is automatically generated in conformity with the designated IOD based on genetic algorithm. The model automatically generates the buildings distribution pattern that meets the conditions through evolutionary computation. Planners and architects can carry out the buildings planning in green spaces more effectively by referring to the generated pattern.

2. Definition and calculation of quantitative index of distribution

2.1. DEFINITION OF THE INDEX OF DISTRIBUTION

The definition of the distribution index derives from geography. The distribution of a certain number of objects in a certain area constitutes the geographic pattern. Besides the distribution center, axis and compactness that describe the geographical distribution characteristics, the distribution of the geographic objects constitute the distribution pattern. The layout of geographic objects within the regional area generally changes between completely clustered and completely dispersed and means randomness when they are in the intermediate state (Figure 1) (Mitchell, 2005).
Mitchell (2005) came up with three methods to describe the distribution status of geographical objects: quadrat analysis, the nearest neighbour index and average adjacent point. The Nearest Neighbour Index (NNI) measures how similar the mean distance is to the expected mean distance for a hypothetical random distribution. It is related to the area of the whole region and the number of objects, irrelevant to the shape of the region, and basically not influenced by the edge effect. However, the NNI just differentiates the clustered or dispersed status, but difficult to makes transverse quantitative comparison on the layout of different regional areas and different quantity objects. It is not suitable for the quantitative description of the buildings distribution status within the green space.

The IOD refers to the quantitative index that describes the distribution status of geographical objects, and develops further based on the NNI. It generates the standard quantitative index with horizontal comparability through the specific value with the extreme value.

2.2. CALCULATION OF THE INDEX OF DISTRIBUTION

The calculation of the IOD is conducted based on the calculation of the NNI.

The formula of the NNI $d$:

$$d = d_o - d_e = \frac{\sum c_i}{n} - 0.5 / \sqrt{n / A} \quad (1)$$

$d_o$: the average most adjacent distance in the current distribution status of objects; $d_e$: the average most adjacent distance between the objects at the time of complete random distribution; $c_i$: the shortest distance between No. $i$ object and the most adjacent objects; $n$: the number of objects; $A$: parcel area.

The significance of the NNI is that the distribution status of objects tends to be clustered when the NNI is less than 0; the distribution status of objects tends to be dispersed when the NNI is more than 0; the distribution status of objects completely shows a random situation when the index equals 0.

Based on the NNI, the formula of the IOD $D$ is as follows:

When $d<0$, $D = d / (d_e - d_{\text{min}}) \quad (2)$

When $d>0$, $D = d / (d_{\text{max}} - d_e) \quad (3)$
\( d_{\text{min}} \) signifies the average shortest distance at the time of the most clustered distribution. Its value is divided into two cases: when the object overlap is allowed, the value is 0; when the object overlap is not allowed, the value is the radius of dot objects.

Through such conversion, the value of the IOD will be between -1 and 1, no matter how the regional area or object quantity changes: when \( D<0 \), the distribution status of objects tends to be clustered and it will be more clustered when it gets closer to -1. When \( D>0 \), the distribution status of objects tends to be dispersed and it will be more disperse when it gets closer to 1. When \( D=0 \), the distribution status of objects completely shows a random situation.

2.3. CORRELATION BETWEEN IOD AND BUILDINGS DISTRIBUTION STATUS

In order to verify the correlation between the IOD and the distribution status of buildings within the green space, we wrote the buildings layout simulation program, which can automatically generate a series of buildings distribution states in conformity with the designated IOD on the premise of the designated green space scope and buildings quantity. The algorithm of the program is growing gradually. The buildings are generated one by one and every new generated building should comply with the designated IOD. The simulation result of the program has great randomness, and can contain all buildings distribution states theoretically. Through comparison between the simulation result and the corresponding distribution index, the correlation between the two can be observed effectively.

We set the plot has 32×32 units and 1,024 grids, including 2% construction lands with about 20 grids. With the simulation program, the buildings layout was generated according to the different IOD. Some results are shown in the Figure 2.

![Figure 2. Buildings Distribution Status Diagram of Different IOD.](image)

Figure 2 presents that the description of quantitative IOD on the buildings distribution status is fairly accurate. The IOD objectively reflect the buildings distribution status and demonstrate the possibility of the index in controlling buildings distribution. The planning management department can
control the buildings distribution within the green space only by regulating appropriate IOD and avoid the occurrence of the cases adverse to the landscape effect, such as excessive centralization or excessive dispersion.

2.4. RELATION OF IOD AND GRIDS

The scope of the IOD is -1 ~ 1, and covers all distribution statuses from clustered to dispersed. -1 means that there are no independently existent grids and all grids are adjacent to at least one grid. 1 means that no two grids are directly adjacent, and all grids are evenly distributed within the area.

The calculation of the IOD targets point features. As for the buildings in the green space, it is infeasible to directly transform a building into a point object, because it completely neglects the area difference of buildings and loses the possibility to control the buildings distribution and avoid excessive centralization. Therefore, we replace points with grids in practical calculation and simulation.

Gridding is an effective method that transforms polygons into points. Through confirming the size of grids, the buildings with different areas can be converted into a series of grids and each grid can be considered as an object in the IOD calculation. The size of grids is very important. We find that in the same buildings layout, the smaller the grid unit is, the smaller the calculated IOD is; the bigger the grid unit is, the bigger the calculated IOD is. Therefore, the value standard of the grid size should be confirmed by the type and size of the green space, the distribution trend of scenic spots in the green space and route planning, to make the distribution index operated more practically.

3. Case study

In order to verify the effectiveness of the IOD, and confirm the reasonable value range of grid sizes and IOD, the study respectively chooses the green spaces of Yuhuatai Park and Qingliangshan Park to carry out case verification. The two parks are both comprehensive parks, but differ in scale and the percentage of the buildings area. They are also successful urban park green spaces. We use ArcGIS as the platform to calculate gridding and IOD.

Yuhuatai Park is an important green space in the southern part of Nanjing, China. The park is a typical case that combines natural landscape and cultural landscape (Figure 3). It has many buildings that can reflect cultural landscape.

Yuhuatai Park covers a total area of about 113 hectares. The construction land area covers about 52,000 m². We use different sizes of grid units for gridding and calculate the IOD, and the results are shown in Table 1.
Table 1. IOD calculation of green space buildings in Yuhuatai Park.

<table>
<thead>
<tr>
<th>Grid size</th>
<th>Amount of grids</th>
<th>$d_0$</th>
<th>$d_e$</th>
<th>$d$</th>
<th>$D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>8m</td>
<td>834</td>
<td>9.39</td>
<td>18.42</td>
<td>-9.03</td>
<td>-0.87</td>
</tr>
<tr>
<td>10m</td>
<td>535</td>
<td>13.03</td>
<td>23.01</td>
<td>-9.98</td>
<td>-0.77</td>
</tr>
<tr>
<td>13m</td>
<td>308</td>
<td>17.67</td>
<td>30.28</td>
<td>-12.61</td>
<td>-0.73</td>
</tr>
<tr>
<td>15m</td>
<td>215</td>
<td>21.41</td>
<td>36.29</td>
<td>-14.88</td>
<td>-0.70</td>
</tr>
<tr>
<td>20m</td>
<td>143</td>
<td>27.66</td>
<td>44.50</td>
<td>-16.84</td>
<td>-0.69</td>
</tr>
</tbody>
</table>

The results suggest that the IOD changes as the size of grids changes, but the buildings layout is still excessively clustered, which basically conform to our actual perception. Through inspection, the reasons of the excessively clustered phenomena are that the volumes of some buildings are too large within the park, the individual building area even exceeding 2,000 m$^2$, on the one hand; some buildings complexes like the southeastern corner of the park are excessively dense on the other hand.

Qingliangshan Park is located on the west side of the main city of Nanjing. It is mainly covered by natural mountain forests and has a few human landscape buildings. The green space is a classic case of green space based on natural landscape (Figure 4).

Qingliangshan Park covers a total area of about 19.5 hectares. The construction land area covers about 9,200 m$^2$. We use different sizes of grid units and calculate the IOD, and the results are shown in Table 2.
Table 2. IOD calculation of green space buildings in Qingliangshan Park.

<table>
<thead>
<tr>
<th>Grid size</th>
<th>Amount of grids</th>
<th>(d_0)</th>
<th>(d_e)</th>
<th>(d)</th>
<th>(D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8m</td>
<td>138</td>
<td>9.16</td>
<td>18.65</td>
<td>-9.49</td>
<td>-0.89</td>
</tr>
<tr>
<td>10m</td>
<td>85</td>
<td>12.49</td>
<td>23.80</td>
<td>-11.31</td>
<td>-0.82</td>
</tr>
<tr>
<td>13m</td>
<td>57</td>
<td>18.83</td>
<td>29.17</td>
<td>-10.34</td>
<td>-0.64</td>
</tr>
<tr>
<td>15m</td>
<td>41</td>
<td>23.56</td>
<td>34.27</td>
<td>-10.71</td>
<td>-0.56</td>
</tr>
<tr>
<td>20m</td>
<td>26</td>
<td>43.99</td>
<td>43.03</td>
<td>0.96</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Compared with the calculation result of the Yuhuatai case, the changes in the IOD of Qingliangshan Park are great when different grid sizes are chosen. When the grid size is 20m, the distribution index shows that the buildings layout within the park is random and deviates from the reality apparently. The reason is the northernmost independent building within the park and it is too far from other buildings. Besides, the IOD is rather small when the grid sizes are 8m and 10m, because most of buildings have the large area, which requires a building to be signified with two or more adjacent grids, causing the excessively clustered illusion. When the grid sizes are 13m or 15m, the result looks reasonable and more suitable for our actual perception.

We can draw the following conclusions in combination with the study on the cases of Yuhuatai Park and Qingliangshan Park:

- When the grid size is between 13 ~ 15m, the calculated IOD is suitable for the actual buildings layout;
- As for comprehensive parks, the reasonable value range of the IOD is -0.7 ~ -0.5.

4. Buildings layout generation model based on Genetic Algorithm

Because of the complexity of the calculation of IOD, it is difficult to directly plan the buildings layout to meet the required IOD. The simulation program
used before could not be used to generate the plan at one time and the random growing algorithm is against the specified requirement. Therefore, the study programmed another model based on the genetic algorithm (GA).

4.1. BUILDINGS LAYOUT GENERATION MODEL
The GA is the method that searches the optimal solutions by simulating natural evolution process. The model takes the IOD as the fitness, and solves the buildings distribution suitable for the function through a series of operations like encoding, assessment, selection, crossover and mutation.

The key step is the coding rules of chromosomes in the realization process of algorithm. The genetic algorithm generally uses the binary encoding method. However, in the buildings layout generation model, the chromosomes need to reflect the coordinates of all buildings within green space. Therefore, the encoding method of 2D real number array is used in the model. The encoding method transforms the building blocks into dots according to the standard size, and constitutes a 2D array with X and Y coordinates of the dot. The array is taken as the gene segment of chromosomes, and each gene segment represents an independent building. All building blocks within the green space can be transformed into building dots, so the number of gene segments can be decided in the chromosomes. Based on such rule, the decoding process is relatively simple. Every gene segment can be transformed into corresponding building dots by direct reading so as to use the calculation formula of the IOD, and compare with the set fitness to judge whether it meets the set conditions.

The building blocks need to be converted into dots in the encoding process. When the distance between dots is too small, the building blocks will be overlapped after decoding, which does not conform to the reality. To avoid the occurrence of the case, we added the verification module to prevent building overlapping.

Other major steps in the model are set as follows:
Generate initial population: Generate a certain quantity of buildings distribution plane randomly as the initial population of genetic algorithm. All coordinate values standing for building blocks in the initial population are generated at random, but each population must go through overlapping verification to ensure the population has no repeated building coordinates.
Selection: Calculate the IOD of every individual according to the initial population, and choose the individuals with most adjacent target IOD value as the carriers of “good genes”, enter the next calculation step.
Crossover: Take the optimized individuals as parent population, cross the respective “genes” by twos - the coordinate value of some buildings, and
generate a group of new individuals. The new individuals and the initial parent population constitute a new population. The new population needs to undergo overlapping verification calculation.

Mutation: Choose some individuals from the new population by a certain proportion, reset the coordinate values of some buildings at random. The selection adopts the roulette form, and the variant genes in the variant individuals are selected randomly. The mutated individuals need to undergo overlapping verification calculation.

Judgment: Calculate the IOD of each individual in the new population through optimization, crossover, mutation, and check whether there are individuals in conformity with the setting. If any, output the individuals as the result and finish calculation. If none, it will enter the next loop.

4.2. THE EXPERIMENTAL APPLICATION OF BUILDINGS LAYOUT GENERATION MODEL

In the study, we made a series of experiments for the buildings layout generation model. These experiments are not conducted in practical situations; adopt idealized setting conditions.

The experimental setting conditions: With 13m×13m as the standard building unit, the plot size is 32×32 units. The relevant parameters in the model are: The initial population number is 100; the optimization rate is 50%; the gene crossing point is the intermediate point of the chromosome length; the mutation rate is 30%; 25% genes of variation individuals varied. According to the setting, the program can soon converge and find the buildings layout plane in conformity with IOD. Figure 5 shows the experiments results with constant IOD and different amount of building units.

![Figure 5. The buildings layout with different amount of building units, IOD is -0.6.](image)

Through experiments, normally, the number of calculating the required reproduction generations is about 60. The operating efficiency of the model is very high.

Further experiments showed that on the premise of not changing other parameters, reducing the number of initial population has not much influence on calculating the number of required reproduction generations, but due to the reduction of the overall calculation amount, the calculation efficiency
can be better improved. If lowering the mutation rate, the number of the reproduction generations will be significantly increased, so the calculation efficiency is reduced.

5. Conclusion and discussion

Through process simulation and case study, the relation between the IOD and the distribution status of buildings in the green space is verified in the theoretical and practical aspects. Through the reasonable value of the IOD, the planning management department can control the state of the buildings layout in green space. On the other hand, the IOD is responded to diverse distribution of buildings. That means the index has numerous space for the design.

Based on the genetic algorithm, the buildings layout generation model can quickly generate the buildings layout plan in conformity with the specified IOD. The calculation result has a certain organic characteristic, higher diversity and can be taken as the important reference and guidance for building layout design, which is of stronger practical value in improving the reasonable distribution of buildings planning in green space.

Only with the IOD as the objective function is the constraint condition of the model relatively singular, making the calculation result also quite random and lacking in sufficient pertinence. The study mainly focused on the geometric significance of the buildings. The building types are ignored now. Moreover, in the practical green space project, the buildings planning will also be influenced by various factors, such as the terrain, area and shape of the green space, the entrances and the paths of the green space, and the original buildings in the green space. Some areas even cannot be set up with buildings absolutely, like the water area. And the original buildings in green space also must be covered in the calculation. In the current model framework, corresponding setting is still lacking for these restrictive and practical conditions.

The further research will expand the objective function and build multi-condition judgment model so that the model can deal with more restrictive conditions, thus with more pertinence and practical significance.

References

