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Spatial planning method of urban landscape architecture distribution pattern based on evolutionary algorithm

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Abstract: Aiming at the problems of low planning accuracy and long planning time in the traditional spatial planning method of urban landscape architecture distribution pattern, a spatial planning method of urban landscape architecture distribution pattern based on evolutionary algorithm was proposed. First, we acquire urban landscape remote sensing images through ETM+ and Landsat TM/OLI images, and use ENVI software to conduct geometric correction, image enhancement and other image processing. Then, we acquire spatial data of landscape distribution pattern from urban landscape green space types, patch area size, number and other aspects. We then use differential evolution algorithm to calculate the fitness value corresponding to the initialised population, extract landscape features, and use mutation operators. The optimal solution is obtained through the three steps of crossover operator and selection operation, which is the optimal spatial planning strategy. The simulation results show that the proposed method has higher precision and shorter planning time in spatial planning of urban landscape architecture distribution pattern.

Keywords: evolutionary algorithm; urban landscape architecture; distribution pattern; spatial planning; landscape characteristics.

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1 Introduction

With the continuous development of urban economy and society, the demand for land has gradually increased, resulting in the reduction of the available area of green space and the reduction of urban environmental carrying capacity. Based on people's use and practice of natural landscape, design urban landscape architecture (Ding, 2019). However, due to the unreasonable landscape design in most urban landscape gardens, the utilisation rate of public space is reduced, which affects the urban environmental construction. Therefore, in order to mitigate the impact on the environment, improve the environmental quality and enhance the utilisation rate of urban space, it is necessary to plan the distribution pattern of urban landscape architecture (Wang et al., 2019).

Liu and Liu (2020) proposed the ecological space elastic planning method of landscape architecture distribution pattern based on ecological security. By analysing the factors that affect the ecological security pattern of landscape architecture, the ecological space security evaluation system of landscape architecture distribution pattern was constructed, the ecological space security evaluation index was obtained, and the index weight was calculated. Based on this, the ecological space elastic planning model of landscape architecture distribution pattern was established. Zhou and Zheng (2022) determine the topological structure of the system. According to the principles of establishing the system database and the data to be stored, the system database is established from the two aspects of data relationship and data type, and the system planning process of digital landscape architecture is designed to enable the system to have the function of planning digital landscape architecture. However, the accuracy of the above two methods for spatial planning of urban landscape architecture distribution pattern is low, resulting in poor planning results. Luo et al. (2019) proposed a local landscape planning method based on ecological cultural spatial correlation, analysed the spatial correlation of urban landscape distribution pattern, classified the local landscape according to the analysis results, and built a local landscape planning model based on the classification results. However, the above methods take a long time to carry out spatial planning of urban landscape architecture distribution pattern, resulting in low planning efficiency.

Differential evolution (DE) algorithm is an efficient global optimisation algorithm. It is also a heuristic search algorithm based on population. Each individual in the group corresponds to a solution vector. Differential evolutionary algorithm is also an optimisation algorithm based on modern intelligence theory, which guides the direction of optimisation search through the swarm intelligence generated by the mutual cooperation and competition among individuals within the population. The operation process of DE algorithm is relatively simple, and the optimal solution can be obtained through DE algorithm, thus improving the accuracy and operation efficiency. Aiming at the problems existing in the above methods, this paper proposes a spatial planning method of urban landscape architecture distribution pattern based on evolutionary algorithm. Through simulation experiments, it can be seen that the proposed method can quickly and accurately plan the urban landscape architecture distribution pattern, solve the problems existing in traditional methods, and lay a certain foundation for urban landscape architecture construction. The specific route of this method is as follows:

1 The remote sensing image of urban landscape was collected by combining ETM+ and Landsat TM/OLI images, but the collected image was affected by the outside world, resulting in data errors. Therefore, ENVI software was used to pre-process the collected image through geometric correction, image enhancement and other steps.

2 According to the remote sensing image processing results of urban landscape architecture, the characteristics of urban landscape architecture are analysed in different ranges and levels, and the spatial data of landscape architecture distribution pattern, such as patch number index, patch type area index, average patch area index, are obtained.

3 According to the spatial data of urban landscape distribution pattern obtained, the DE algorithm is used to extract the characteristics of urban landscape architecture. Based on different landscape characteristics, the differential variation is carried out through three variation mechanisms, namely, random difference vector method, optimal solution plus random vector difference method, and optimal solution plus random vector difference method. After the operation of the variation operator is completed, the crossover operation is carried out. Finally, the search method is used; the solution is the spatial planning strategy for the distribution pattern of urban landscape architecture.

2 Spatial planning method of urban landscape architecture distribution pattern

2.1 Remote sensing information sources and image processing

Landsat8 is composed of land imager and thermal infrared sensor, with high spatial resolution and panchromatic band resolution. Therefore, this paper collects remote sensing images of urban landscape through ETM+ and Landsat TM/OLI images (Tian et al., 2019; Cheng et al., 2020).

Because the height, vibration or atmospheric refraction, ground curvature of the satellite sensor itself will affect the satellite's remote sensing imaging, which will inevitably lead to data errors, resulting in inaccurate acquisition of spatial data of urban landscape distribution pattern. Therefore, in order to more clearly highlight the differences between various green spaces and ground objects when obtaining information from remote sensing images, geometric correction image enhancement and band combination are three steps to pre-process the collected remote sensing image, so as to achieve the most real reflectivity and finally obtain more accurate and effective green space information. The specific steps are as follows:

1 Geometric correction: there are two factors that can affect the geometric deformation of images in the process of satellite image acquisition. One is the systematic deformation caused by the sensor itself, and the other is the unsystematic deformation caused by the stability of the satellite sensor, the earth's topography, atmospheric refraction, etc. Use the image to image tool in ENVI software to complete the correction of urban landscape remote sensing images (Zhang et al., 2019).

2 Image enhancement: in order to enhance the image difference between various objects, ENVI software needs to be used to increase the saturation and linearity of the greyscale histogram of the remote sensing image when interpreting the remote sensing image, and finally the contrast between the objects will be enhanced. Enhanced for easier access to graph information.

3 Band combination: the image information obtained by the satellite sensor is formed by the combination of several different bands. The specific band combination has a relatively good feedback on the specific feature information, which can make different features present a more obvious level easier to interpret.

2.2 Spatial data acquisition of urban landscape architecture distribution pattern

To study the distribution pattern of urban landscape architecture, it is necessary to select multiple indexes according to the actual situation of the study area from different angles, and determine the rationality of the distribution pattern of urban landscape architecture by quantifying the relationship between the structural characteristics of urban space and the layout of landscape architecture. The study of landscape green space patch correlation index is the basis for establishing the landscape pattern index in the study. The landscape pattern index mainly analyses the correlation and fragmentation of landscape green space patches from the overall urban matrix, so selecting appropriate and reasonable landscape index is a very important and scientific step for analysing the distribution pattern of urban landscape (Chen et al., 2019).

Based on the above remote sensing image processing results, this paper analyses the characteristics of urban landscape architecture and the spatial data of urban landscape architecture distribution pattern in different areas and levels from the aspects of the types of landscape architecture green space and patch size, number, and spatial distribution of the whole city. The scientific and reasonable quantitative analysis of urban landscape architecture is carried out from the two levels of patch level type and landscape level type, and the advantages and disadvantages of urban landscape architecture distribution pattern are analysed based on the spatial data of urban landscape architecture distribution pattern obtained, so that the theory and application of landscape ecology can be combined to comprehensively reflect that the correlation between urban landscape green patches plays a key role in the spatial planning of urban landscape architecture distribution pattern (Peng et al., 2021).

1 Number of plaques

NP represents the total number of patches (a patch type), and its range value is $NP \geq 1$. The number of patches index can reflect the fragmentation of urban landscape. The smaller the number of patches, the smaller the fragmentation of urban landscape. This index is the basis for the calculation of all other landscape indices.

$$NP = N \tag{1}$$

where N represents the total number of plaques.

2 Patch type area

If the plaque type is i and the number of patches is j, then:

$$CA = \sum_{j=1}^{n} a_{ij} \left(\frac{1}{10,000} \right) \quad (2)$$

CA is the total area of patches of the same type of landscape in urban landscape architecture, where a_{ij} is the patch area, and its range value is $CA > 0$. Patch type area index can be used to describe the characteristics of landscape components, which has important ecological significance.

3 Average plaque area

If the area of patches of the same type of urban landscape is set as A_i, then:

$$MPS = \frac{A_i}{N} \quad (3)$$

MPS represents the average area size of a certain patch type. It analyses the difference between different types of patches. The smaller the patch area of the same types of landscape in urban landscape architecture, the higher the landscape fragmentation. The index can also reflect the complexity of landscape spatial structure and the changes of landscape heterogeneity (Han et al., 2019).

4 Plaque density

$$PN = \frac{N}{A} * 10,000 * 100 \quad (4)$$

PN is the density of urban landscape patches, *A* is the sum of the area of this type of patches, and the value range is $CA > 0$. The index value can also affect biological protection and energy distribution.

5 Percentage of patch area in landscape type

$$PLAND = \frac{\sum_{j=1}^{n} a_{ij}}{A} * 100 \quad (5)$$

In the formula, *A* can mainly be used to judge the dominant patch types in the landscape (Young et al., 2019).

6 Maximum plaque area

$$LPI = \frac{\text{Max}(a_1, ..., a_n)}{A} * 100 \quad (6)$$

LPI refers to the extent to which the overall landscape is occupied by large patches, $\text{Max}(a_1, \ldots, a_n)$ refers to the maximum area of patch type n of a certain type of patch, and *A* refers to the total area of landscape type *n*. *LPI* is used to determine the richness of dominant species, and can also show the intensity of human interference.

7 Abundance density

$$PRD = \frac{m}{A} 10^6 \quad (7)$$

PRD mainly represents the spatial heterogeneity of a landscape, and *m* represents the number of patch types.

8 Landscape shape index

Set the patch perimeter as *kE*:

$$LSI = \frac{kE}{\sqrt{A}} \tag{8}$$

LSI represents the complexity of patch shape in the landscape pattern. When $LSI = 1$, the landscape patch consists of only one rectangular patch; When the index value is larger and LSI increases unrestricted, the edge effect on the surrounding environment is greater (Dai et al., 2020).

9 Landscape fragmentation index

$$C_i = \frac{N_i}{A_i} \tag{9}$$

where C_i refers to the density index of landscape corresponding to landscape green patch *i*, and N_i refers to the number of landscape green patches *i*. The larger the C_i value, the higher the fragmentation of human landscape.

10 Shannon landscape diversity index

If the ratio of landscape architecture and total landscape area of class *i* is p_i, and the number of landscape green space types is *m*, then:

$$SHDI = -\sum_{i=1}^{m} p_i \ln(p_i) \tag{10}$$

When the landscape contains only one type, the landscape is homogeneous, and its $SHDI = 0$; when the landscape contains multiple types and the proportion of each landscape is the same, the *SHDI* value is the highest. The higher the landscape diversity index, the more balanced the proportion of landscape area.

11 Shannon landscape evenness index

$$SHEI = \frac{-\sum_{i=1}^{m} p_i \ln(p_i)}{\ln m} \tag{11}$$

When Shannon landscape evenness index is close to 1, it indicates that the evenness of landscape pattern is high and the landscape dominance is low; when SHEI is small, it indicates that it is composed of only one or several landscape types, with high landscape dominance and diversity (Xu et al., 2019a).

12 Landscape dominance index

If the maximum diversity index of urban landscape architecture is set as $Hmax = \ln(n)$, then:

$$LDI = Hmax + \sum_{i=1}^{n} p_i \ln(p_i) \tag{12}$$

Landscape dominance is used to judge the degree to which landscape types dominate the overall landscape.

13 Aggregation index

If the number of similar adjacent patches is set as g_i, then:

$$AI = \frac{g_i}{\max g_i} * 100 \tag{13}$$

With the increase and decrease of aggregation index, the aggregation of various patches of urban landscape architecture is also increasing and decreasing.

2.3 Spatial planning based on evolutionary algorithm

In this paper, the engineering problem of spatial planning of urban landscape architecture distribution pattern is transformed into a mathematical optimisation problem, and the DE algorithm is an optimisation algorithm based on global search. Therefore, the evolution algorithm selected in this paper is the DE algorithm. Using this algorithm to plan the spatial planning of urban landscape architecture distribution pattern, first extract the landscape characteristics, and based on different landscape characteristics, the optimal solution is calculated through three steps of mutation operator, crossover operator and selection operation to obtain the optimal spatial planning strategy (Xu et al., 2019b). The specific steps are as follows:

2.3.1 Extract landscape features

According to the spatial data of urban landscape distribution pattern obtained above, landscape features are extracted, and appropriate spatial planning strategies are selected based on different landscape features (Zhang, 2021).

First, calculate the fitness value ($fitness_{1,g}$, $fitness_{2,g}$, …, $fitness_{NP,g}$) corresponding to the initialised population $X_g = (X_{1,g}, X_{2,g}, \ldots, X_{NP,g})$.

Step 1 Find out the individual x_{best} corresponding to $fitness_{best}$.

Step 2 Calculate the distance d_i between x_i and x_{best} of all individuals in the population:

$$d_i = \sum_{j=1}^{D} \left| x_{ij} - x_{bestj} \right| \tag{14}$$

Step 3 Arrange $d_1, d_2, \ldots, d_{NP}$ in ascending order and record it as $k_1, k_2, \ldots, k_{NP}$.

Step 4 Initialise $c = 0$ and compare all k_i from front to back. If $f_{k_{i+1}} + \varepsilon \le f_{k_i}$ (ε is the error value and $f(\cdot)$ is the fitness function), then $c = c + 1$.

Step 5 Regularise c to get the landscape characteristics of fitness:

$$\varphi = \frac{c}{NP - 1} \tag{15}$$

2.3.2 Mutation operator

For the distribution pattern space of urban landscape architecture, in the early stage of evolution, because the individuals in the population are scattered, the local fitness landscape is closer to the multimodal model; In the later stage, the differences between individuals gradually decrease and are concentrated in areas with high fitness values, so the local fitness landscape is closer to the unimodal model (Yang et al., 2020). According to the characteristics of mutation operator and local fitness landscape, when the landscape presents or approaches a multimodal model, *DE*/*best*/1 mutation operator is used, while when the landscape presents or approaches a unimodal model, *DE*/*rand-to-best*/1 mutation operator can improve the convergence speed and accuracy of the algorithm (Wang et al., 2021).

Set the scaling factor as F, and carry out differential variation through the variation operator. The variation operator operation mainly includes the following three types of variation mechanisms, namely, the random difference vector method, the optimal solution plus random vector difference method, and the optimal solution plus random vector difference method. With the spatial planning time of urban landscape distribution pattern as the optimal, differential variation is carried out through the above three types of variation mechanisms to build the objective function:

a *DE*/*rand*/1

$$V_i = X_{r1} + F\left(X_{r2} - X_{r3}\right) \tag{16}$$

b *DE*/*best*/1

$$V_i = X_{best} + F\left(X_{r1} - X_{r2}\right) \tag{17}$$

c *DE*/*rand-to-best*/1

$$V_i = X_i + F\left(X_{best} - X_i\right) + F\left(X_{r1} - X_{r2}\right) \tag{18}$$

In the formula, V_i represents the target vector, X_i represents the mutation vector, $r1$, $r2$, $r3$ represents the randomly selected integer, and X_{best} represents the best individual of the current generation.

2.3.3 Crossover operator

After the mutation operator operation is completed, cross operation is carried out, and the target function is constructed with the spatial planning accuracy of urban landscape architecture distribution pattern as the best. The specific steps are as follows:

Step 1 Generate probability distribution $\pi = (\rho(CR_{Gaussian,g}), \rho(CR_{Gauchy,g}))$ according to the size of fitness landscape feature φ, where $\rho(CR_{Gaussian,g})$, $\rho(CR_{Gauchy,g})$ represents the probability of using the hybrid probability (Gong et al., 2021).

Step 2 Use rand function to generate a random number and $rand \in [rand]$.

Step 3 If $0 \le rand \le \varphi$, use $CR_{Gaussian,g}$ for cross operation; otherwise, skip to step 4.

Step 4 Use $CR_{Gauchy,g}$ for cross operation.

2.3.4 Select action

After the above operations, select, and compare the test vector $u_{i,G}$ with the target vector $v_{i,G}$ through the search method. If the adaptive value is better, it will be saved to the next generation (Marull et al., 2020). The specific operation is as follows:

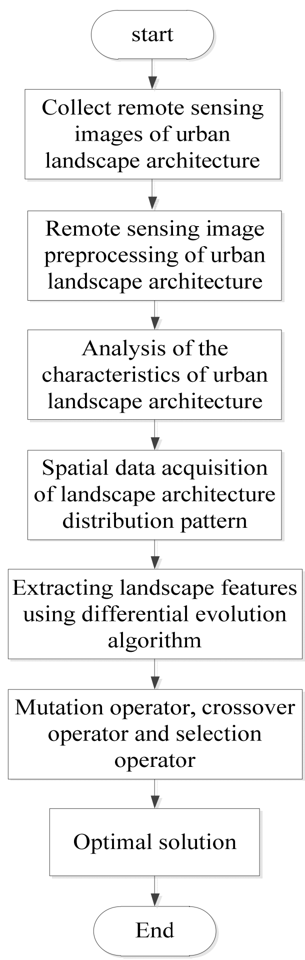
$$X_{i,G+1} = \begin{cases} u_{i,G}, \text{if } f\left(u_{i,G}\right) \leq f\left(v_{i,G}\right) \\ v_{i,G}, \text{if } f\left(u_{i,G}\right) > f\left(v_{i,G}\right) \end{cases} \tag{19}$$

where $X_{i,G+1}$ represents the individual vector of the new population.

The above steps are iterated until the optimal solution is obtained, which is the spatial planning strategy of urban landscape architecture distribution pattern.

To sum up, the specific process of the spatial planning method of urban landscape architecture distribution pattern based on evolutionary algorithm proposed in this paper is shown in Figure 1.

Figure 1 Specific flow chart of this method



3 Simulation experiment analysis

In order to verify the effectiveness of the spatial planning method of urban landscape architecture distribution pattern based on evolutionary algorithm proposed in this paper in practical application, a central urban landscape architecture is selected as the experimental object, and the precision and efficiency of spatial planning of urban landscape architecture distribution pattern are taken as the experimental indicators. The method of Liu and Liu (2020) and the method of Wang et al. (2020) are used as the comparison methods to conduct a simulation experiment analysis with this method. Set the experimental parameters of the evolutionary algorithm, as shown in Table 1.

Table 1 Experimental parameter setting

	Parameter
Population quantity	20*10
Population size	200
Global iterations	50
Optimisation speed	0.6 MIPS
Threshold of random function	(0, 1)
Dimension	20
Number of independent runs	100
Search domain	[–100, 100]

Use Fragstats software to calculate various landscape indexes of remote sensing images of landscape architecture in the central urban area in 2021, and obtain spatial data of urban landscape architecture distribution pattern, as shown in Table 2.

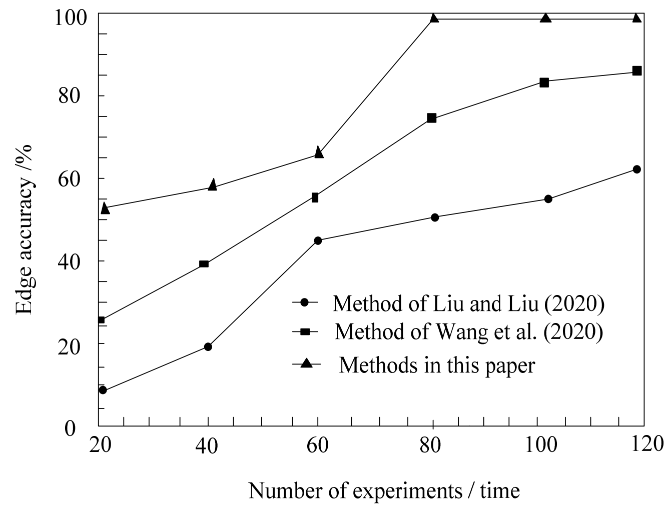
Table 2 Spatial data of urban landscape architecture distribution pattern in 2021

	CA	*PLAND*	*NP*	*PD*	*LPI*	*LSI*	*MPS*	*PAFRAC*
Park green space	1,798.92	4.792	366	0.975	0.876	19.731	4.915	1.330
Protective green space	5,072.52	13.512	1,263	3.365	0.813	43.838	4.016	1.395
Square green space	439.11	1.170	285	0.759	0.155	18.593	1.541	1.341
Affiliated green space	10,557.54	28.125	5,344	14.236	0.874	76.604	1.976	1.345
Regional green space	19,866.95	52.401	998	2.659	6.632	36.934	19.709	1.342

In order to verify the effectiveness of the method in this paper, the spatial planning method of urban landscape architecture distribution pattern based on evolutionary algorithm, method of Liu and Liu (2020) and method of Wang et al. (2020) proposed in this paper are used to compare and analyse the spatial planning accuracy of urban landscape architecture distribution pattern. The comparison results are shown in Figure 2.

According to Figure 2, the spatial planning method of urban landscape architecture distribution pattern based on evolutionary algorithm proposed in this paper can achieve the highest accuracy of 98% for urban landscape architecture distribution pattern spatial planning, while the accuracy of method of Liu and Liu (2020) for urban landscape architecture distribution pattern spatial planning is only 63%, and the accuracy of method of Wang et al. (2020) for urban landscape architecture distribution pattern spatial planning is only 86%, The spatial planning method of urban landscape architecture distribution pattern based on evolutionary algorithm proposed in this paper has the highest accuracy.

Figure 2 Comparison results of spatial planning accuracy of urban landscape architecture distribution pattern



In order to further verify the effectiveness of the method in this paper, the method in this paper, the method in Liu and Liu (2020) and the method in Zhou and Zheng (2022) are used to make a comparative analysis of the time used for spatial planning of urban landscape architecture distribution pattern. The comparison results are shown in Table 3.

Table 3 Spatial planning time of urban landscape architecture distribution pattern/s

Number of experiments/time	*Methods in this paper*	*Method of Liu and Liu (2020)*	*Method of Wang et al. (2020)*
10	6.25	15.05	22.36
20	6.77	15.96	22.75
30	7.24	16.12	23.64
40	7.84	17.25	23.98
50	8.95	17.95	24.12
60	9.24	18.64	24.63
70	9.85	19.24	25.34
80	10.11	20.65	25.35
90	11.64	21.69	26.98
100	11.95	21.75	27.42

According to the data in Table 3, the time used for spatial planning of urban landscape architecture distribution pattern in this method is 11.95 s, 21.75 s in, and 27.42 s in Zhou and Zheng (2022), the method in this paper takes the shortest time and the highest efficiency in spatial planning of urban landscape architecture distribution pattern.

4 Conclusions

Because of the poor effect and low efficiency of the traditional methods of urban landscape architecture spatial planning, this paper studies the method of urban landscape architecture spatial planning through evolutionary algorithm. Because the remote sensing image of urban landscape obtained from ETM+ and Landsat TM/OLI images is affected by the outside world, resulting in unclear images, the remote sensing image of urban landscape is pre-processed by geometric correction, image enhancement and band combination. Based on the pre-processed results, spatial data of urban landscape distribution pattern is obtained by analysing landscape characteristics, and DE algorithm is used, spatial planning for the distribution pattern of urban landscape architecture. The experimental results show that the accuracy of the proposed method for spatial planning of urban landscape architecture distribution pattern is up to 98%, and the planning time is within 11.95 s. The accuracy of urban landscape architecture distribution pattern spatial planning is high, and the planning time is short.

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