RESEARCH ARTICLE

Research on urban garden landscape design based on vegetation diversity characteristics

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With the acceleration of urbanization, urban landscape design plays an increasingly important role in enhancing the ecological environment, beautifying the cityscape, and promoting the physical and mental well-being of residents. As a fundamental component of garden landscapes, vegetation directly influences the ecological benefits, aesthetic value, and functional diversity of these landscapes. However, conventional evaluation methods rely on on-site observations by individuals and are limited by subjective perspectives. To more efficiently identity the diversity characteristics in garden landscapes and conduct evaluations, this research used unmanned aerial vehicles (UAVs) to capture images of landscape vegetation and employed a K-means clustering algorithm to classify the vegetation within these images. Moreover, the vegetation diversity indices including richness index, dominance index, diversity index, and evenness index were calculated. Semantic difference analysis was used to evaluate the design of the garden landscape. An ancient tree park located in Hongmiaobian Village, Jukoupu Town, Xinshao County, Shaoyang City, Hunan Province, China was taken as a case study. The proposed method was compared with two other classification algorithms including random forest and support vector machine. The results showed that the K-means algorithm identified and classified vegetation areas in remote sensing images more accurately. The ancient tree park had high vegetation diversity. However, it had some shortcomings in its overall landscape design. This research adopted UAVs to quickly collect more comprehensive landscape images, using an intelligent algorithm to rapidly classify vegetation areas and calculate diversity, and evaluating landscape design, providing an effective reference for improving the quality of landscape design.

Keywords: vegetation diversity; garden; landscape design; semantic difference analysis.

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Introduction

Urbanization will inevitably have adverse effects on the original ecological environment. Although these impacts can be mitigated through thoughtful planning, they will eventually affect the original environment [1]. Urban gardens serve as a strategy for ecological protection during the urbanization process. In essence, during urbanization, ecological areas that require protection are divided, and their landscapes are carefully planned and designed [2]. After planning and design, urban garden landscapes can not only safeguard the ecological environment within the city but also serve as scenic spots that promote the development of the local tourism economy. The effectiveness of urban gardens in protecting ecology and enhancing the tourism economy largely depends on the quality of the landscape design schemes implemented. Increasing the diversity of vegetation in gardens can enhance the stability of the ecological environment and improve the variety of landscapes, thereby attracting more tourists [3]. Urban gardens with effective landscape design can be used as tourist attractions, stimulating the development of the local tourism economy [4]. The internal landscape design of an urban garden is crucial. During the landscape design process, evaluating the quality of the design is a significant reference point [5]. In this evaluation, the characteristics of vegetation diversity are a key index. Plant diversity refers to the richness and variety of plant species in a region, reflecting the complexity and stability of the ecosystem in the region, and its characteristics mainly include species diversity, community structure complexity, and spatial distribution heterogeneity. The characteristics of plant diversity are affected by natural factors such as climate, soil, and topography, as well as human factors like urban planning and landscape design. It not only assesses the quality of landscape design but also indicates the health of the green space ecosystem within gardens [6].

The traditional evaluation method for garden landscapes involves dividing the sample land into plots, conducting field investigations to collect data related to landscape design, and performing a comprehensive evaluation of the garden's landscape. This approach is quite time-consuming and, since data collection is limited to the selected plots, the resulting data may not be sufficiently comprehensive. However, with advancements in unmanned aerial vehicle (UAV) technology, UAVs equipped with cameras can be used for data acquisition in garden landscape assessments. These UAVs can fly at various altitudes, capturing images of the garden, which can then be analyzed to evaluate the landscape design. Compared to traditional evaluation methods, UAVs not only offer greater efficiency in collecting landscape images but also are not affected by terrain variations, so it can collect more comprehensive data [7].

Santos *et al.* examined the effects of local variables including fertility and litter amount and landscape variables including patch shape, compositional heterogeneity, habitat amount, matrix dominance, and connectivity on alpha species richness, diversity, and the basal area of various vegetation types including forest savanna, savanna, and forest in the Cerrado using linear models and the Akaike information criterion [8]. Polat *et al*. studied how the visual quality of urban recreational areas was associated with the structural and vegetative landscape elements within these areas, as well as the preferences of visitors and users [9]. Behera *et al.* analyzed the patterns of plant diversity along India's longest longitudinal range, spanning from desert to wet tropical zones utilizing field data collected from the national-level 'Landscape Level Biodiversity Characterization' project and found that vegetation types transitioned from tropical thorn to tropical moist/wet evergreen forest [10].

Those previous studies had all analyzed landscape diversity. However, most of these studies focused on landscapes in large regions, resulting in a macroscopic perspective. This research analyzed urban garden landscapes specifically using UAVs to capture images of garden vegetation and the K-means clustering algorithm to categorize the vegetation within these images. Moreover, the vegetation diversity index was calculated. The semantic difference analysis was used to evaluate the garden landscape design. An ancient tree park located in Hongmiaobian Village, Jukoupu Town, Xinshao County, Shaoyang City, Hunan Province, China was taken as a case study for analysis. The result of this research supported the utilization of a clustering algorithm to classify the landscape features collected by UAVs to calculate the vegetation diversity and to assess the quality of landscape design using the semantic difference analysis method.

Materials and methods

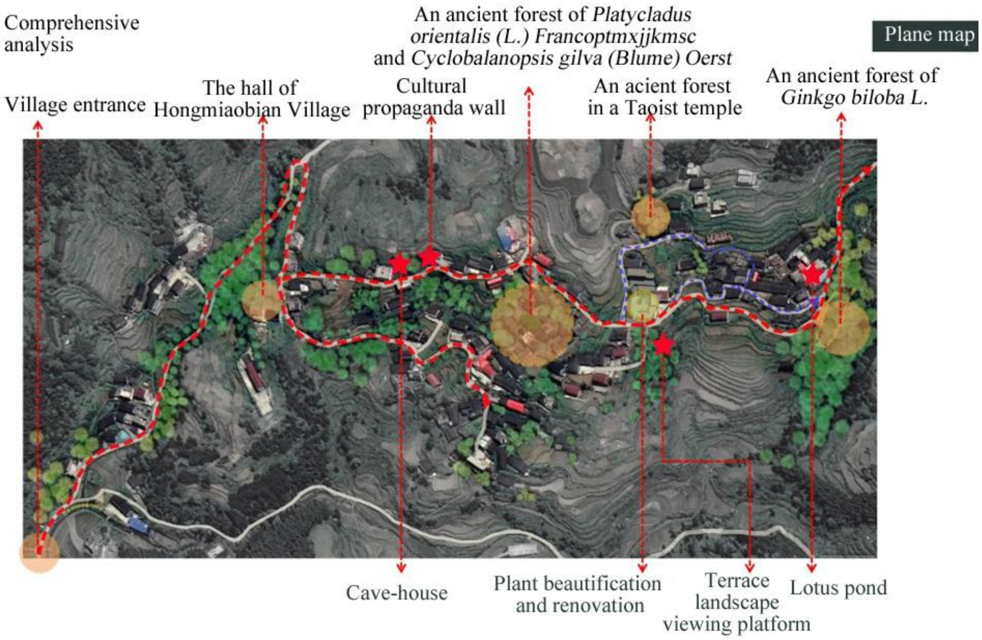

Figure 1. The plane map of the ancient tree park in Hongmiaobian Village, Jukoupu Town, Shaoyang, Hunan, China.

Overview of the study area

This research took the ancient tree park located in Hongmiaobian Village, Jukoupu Town, Xinshao County, Shaoyang City, Hunan Province, China (111.31° E, 27.42° N) as the study area with the terrain higher in the north and lower in the south, predominantly consisting of mountains and hills and a main river, Shunshui River (Figure 1). The area is a subtropical zone with a typical central Asia subtropical humid monsoon climate.

Measurement of the vegetation diversity characteristic index in the park

DJI Mini 4 Pro (Dajiang Innovation Technology Co., Ltd., Shenzhen, Guangdong, China) was used to collect low-altitude remote sensing images of the ancient tree park with GPS + Galileo + BeiDou navigation system. The UAV equipped a 48 million effective pixels camera, which could take maximum size of 8,064 × 6,048 photos. The UAV could withstand wind speeds up to level 5 and the longest flight time was 34 minutes. The park was divided into four distinct areas for targeted data collected by the UAV. The remote sensing maps of the four zones were integrated to create a comprehensive map of the entire park.

After the urban garden images were collected by UAVs, the plant area zones in the images were identified and classified, and then the vegetation diversity in the garden was calculated according to the number of plants in each plant zone (the number of plants in the zone was represented by the zone area). The images of the garden were filtered and preprocessed to reduce the "noise" in the images [11]. The filtering equation was as below.

$$G(x,y)=\frac{\exp\left(-\frac{x^2+y^2}{2\delta^2}\right)}{2\pi\delta^2} \quad (1)$$

where (x, y) was the pixel point in the image. δ was for the standard deviation. The vegetation area in the image was then divided by the K-means clustering algorithm [12]. The K cluster centers were randomly selected, and the feature distance between other pixels and the cluster center was calculated for the nearest distribution. The mean value of each class was then taken as the new cluster center for the nearest distribution again [13]. The gradient of pixels was used as the feature to calculate the feature distance in this study. The gradient of pixels included gradient value, gradient modulus value, and gradient direction. Their corresponding calculation formulas were as follows.

$$\begin{cases} grad\ I(x,y) = \left(\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}\right) \\ m(x,y) = \sqrt{(L(x+1,y)-L(x-1,y))^2 + (L(x,y+1)-L(x,y-1))^2} \\ \theta(x,y) = \tan^{-1}\left[\frac{L(x,y+1)-L(x,y-1)}{L(x+1,y)-L(x-1,y)}\right] \end{cases} \quad (2)$$

where $grad\ I(x,y)$ was the gradient of pixels. $m(x,y)$ was the modulus value that corresponded to the pixel gradient. $\theta(x,y)$ was the direction that corresponded to the pixel gradient. $L(x,y)$ was the grayscale of the pixel. After classifying and identifying plant regions in low-level remote sensing images by the classification algorithm, the characteristics of plant diversity were calculated as below.

$$\begin{cases} D_M = \frac{S-1}{\ln(N)} \\ H = -\sum_{i=1}^{S} P_i \ln(P_i) \\ D = 1 - \sum_{i=1}^{S} P_i^2 \\ J = -\sum_{i=1}^{S} \frac{P_i \ln(P_i)}{\ln(S)} \end{cases} \quad (3)$$

where D_M was the richness index. H was the diversity index. D was the dominance index. J was the evenness index. S was the number of species in the area. N was the number of individuals of all species in the area, expressed by the occupation area in this study. P_i was the proportion of the i-th category of species among all species. The relevant parameters of the K-means clustering algorithm used to segment areas in remote sensing images included that the value of K was set to 15, and the maximum number of iterations was 500 times [14]. In addition, this study evaluated two classification algorithms, random forest (RF) and support vector machine (SVM), to verify the performance of the K-means algorithm in segmenting areas within remote sensing images. The relevant parameters for the RF algorithm were the number of decision trees being set to 150 and the maximum number of features being set to 5, while the maximum depth of the decision tree was not restricted. The relevant parameters for the SVM algorithm included the sigmoid kernel function and a penalty parameter of 1. The indicators used to evaluate the classification effect were shown below.

$$\begin{cases} AA = \frac{\sum_{i=1}^{n} \frac{C_i}{T_i}}{n} \\ OA = \frac{\sum_{i=1}^{n} C_i}{T} \\ Kappa = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \cdot x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \cdot x_{+i})} \end{cases} \quad (4)$$

where AA was the average accuracy. OA was the overall accuracy. $Kappa$ was the overall accuracy of classification. n was the total number of categories. T_i was the total number of pixels in category i. C_i was the number of correctly categorized pixels in category i. x_{ii} was the number of pixels in the i-th row and i-th column of the matrix. r was the number of rows in the confusion matrix. N was the total number of pixels. x_{i+} was the total number of pixels in the i-th row. x_{+i} was the total number of pixels in the i-th column.

Landscape design evaluation of the park using semantic difference analysis

The vegetation diversity in gardens was calculated based on the remote sensing images of gardens, which provided objective reference data for evaluating the quality of landscape design. However, due to the ornamental function

Table 1. Adjective pairs of garden landscape characteristic elements.

Landscape characteristic	Adjective pair	Landscape characteristic	Adjective pair
Element richness	Single - diverse	**Naturalness**	Artificial - natural
Regularity of landscape	Irregular - regular	**Plant morphology**	Single - diverse
Vegetation diversity	Single - diverse	**Vegetative texture**	Rough - fine
Vegetation coverage	Low - high	**Seasonal characteristics**	Blur - obvious
Range of vision	Narrow - broad	**Canopy line changes**	Monotonous - rich
A sense of layering	Blur - clear	**Coordination**	Unbalance - coordinated

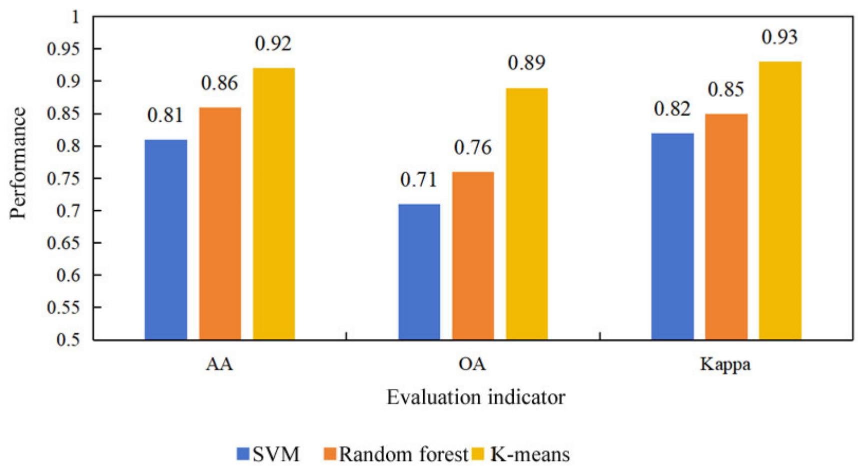

Figure 2. Performance of three classification algorithms for dividing areas on remote sensing images. AA: the average accuracy. OA: the overall accuracy. Kappa: the overall accuracy of classification.

of the garden itself, the objective vegetation diversity feature index alone could not fully reflect the quality of landscape design, especially in terms of visual experience [15]. Therefore, this study adopted the semantic difference analysis method to evaluate landscape design [16]. In the analysis of semantic difference, the choice of adjective pairs used to evaluate the feature elements of garden landscape was the key. A total of 12 landscape feature elements were selected to evaluate garden landscape design (Table 1). After the adjective pairs were established, the evaluation scale of the adjective pair of feature elements was set. A five-level evaluation scale including -2, -1, 0, 1, 2 was selected [17]. The lower the score, the lower the evaluation in the adjective pair. 30 professional evaluators specializing in landscape design were invited to evaluate the landscape design of the park. Remote sensing images of the park captured by a UAV along with a questionnaire containing the 12 landscape feature elements were provided to the professional evaluators. The 12 landscape feature elements in the questionnaire were evaluated using a five-point scale, and the final comprehensive evaluation results were recorded to obtain a comprehensive evaluation of garden landscape design.

Results and discussion

The performance of the three classification algorithms for dividing areas of vegetation on remote sensing images was shown in Figure 2. The results showed that the K-means clustering algorithm had the best performance followed by the RF algorithm. The SVM algorithm had the worst performance. After the vegetation area division, the vegetation diversity index was calculated (Table 2). The results showed that the diversity of different areas in the park was

Table 2. The area division of the park and the comprehensive vegetation diversity index.

	D_m	*H*	*D*	*J*
Area 1	5.98	2.35	0.878	0.858
Area 2	5.12	2.12	0.847	0.874
Area 3	5.45	2.58	0.864	0.836
Area 4	4.89	2.11	0.836	0.852
Comprehensive	5.36	2.29	0.856	0.855

Notes: D_m: richness index. *H:* diversity index. *D:* dominance index. *J:* evenness index.

Table 3. Landscape design evaluation results of the park.

	Mean	Minimum value	Maximum value	Standard deviation
Element richness	0.45	0.15	0.68	0.12
Regularity of landscape	0.51	0.88	0.68	0.11
Vegetation diversity	0.28	0.23	0.59	0.09
Vegetation coverage	0.25	0.11	0.47	0.03
Range of vision	0.34	0.09	0.54	0.11
A sense of layering	0.36	0.11	0.62	0.12
Naturalness	0.33	0.08	0.58	0.08
Plant morphology	0.48	0.22	0.55	0.02
Vegetative texture	0.33	0.22	0.47	0.03
Seasonal characteristics	0.23	0.01	0.43	0.11
Canopy line changes	0.62	0.31	0.76	0.09
Coordination	0.65	0.32	0.79	0.14

different, but the difference was not very large. The comprehensive richness, diversity, dominance, and evenness indexes were 5.36, 2.29, 0.856, and 0.855, respectively. The richness index (D_m) represented the number of species within a given area and could be used to directly reflect the difference of species richness among different regions. The diversity index (*H*) was insensitive to the size of areas and could reflect the relative abundance among different species within the region. The dominance index (*D*) was the probability that two consecutive samples taken from the same region belonged to the same kind. The evenness index (*J*) represented the degree of consistency of a species in a region at the level of population. The results of the indicators demonstrated that the ancient tree park had a high level of species diversity, and these vegetations were relatively well-distributed.

The evaluation results of landscape design of the park obtained by using semantic difference analysis were shown in Table 3. The results showed that the richness of vegetation elements in the park was relatively high; the landscape design was relatively regular; the vegetation diversity and coverage were medium; the vision was relatively broad; the vegetation landscape design was relatively hierarchical and natural; the plant morphology and texture were relatively rich and delicate; the seasonal characteristics were relatively obvious; the forest canopy line changes were abundant; and the coordination was relatively good. The method of semantic difference analysis first set up positive and negative adjective pairs related to the characteristics of landscape design and then collected evaluations from multiple experts in the form of questionnaires. Due to the subjectivity of evaluations given by different experts, it was necessary to statistically process the collected evaluations. When analyzing, the mean value was used as a measure.

This research used UAV to collect images of garden vegetation. The K-means clustering algorithm was employed to classify the vegetation areas within these images and to calculate the vegetation diversity index. Semantic difference analysis was conducted to evaluate the garden landscape design using an ancient tree park. The results showed that K-means clustering algorithm demonstrated the best performance in classifying vegetation regions followed by the RF algorithm, while the SVM algorithm had the worst performance.

References

1. Setoguchi H. 2017. Conservation and vegetation restoration of coastal plant populations: Perspective from phylogeography and population genetics. Landscape Ecol Manag. 22(2):43-51.
2. Vaissi S. 2021. Design of protected area by tracking and excluding the effects of climate and landscape change: A case study using Neurergus derjugini. Sustainability 13(10):1-20.
3. Wang B, Tian C, Liang YM, Liu WH. 2021. Responses of ground beetle (Coleoptera; Carabidae) assemblages to stand characteristics and landscape structure in riparian poplar forests. Insect Conserv Diver. 14(6):780-792.
4. Easdale MH, Faria C, Hara S, Perez LN, Umana F, Tittonell P, *et al*. 2019. Trend-cycles of vegetation dynamics as a tool for land degradation assessment and monitoring. Ecol Indic. 107(Dec.):105545.1-105545.10.
5. Venter ZS, Scott SL, Desmet PG, Hoffman MT. 2020. Application of Landsat-derived vegetation trends over South Africa: Potential for monitoring land degradation and restoration. Ecol Indic. 113:1-9.
6. Lorenz K, Lal R, Ehlers K. 2019. Soil organic carbon stock as an indicator for monitoring land and soil degradation in relation to United Nations' Sustainable Development Goals. Land Degrad Dev. 30(7):824-838.
7. Prăvălie R, Patriche C, Tişcovschi A, Dumitraşcu M, Săvulescu I, Sîrodoev I, *et al*. 2020. Recent spatio-temporal changes of land sensitivity to degradation in Romania due to climate change and human activities: An approach based on multiple environmental quality indicators. Ecol Indic. 118:106755.
8. dos Santos JS, Silva-Neto CM, Silva TC, Siqueira KN, Ribeiro MC, Collevatti RG. 2022. Landscape structure and local variables affect plant community diversity and structure in a Brazilian agricultural landscape. Biotropica 54(1):239-250.
9. Polat AT, Akay A. 2015. Relationships between the visual preferences of urban recreation area users and various landscape design elements. Urban For Urban Gree. 14(3):573-582.
10. Behera MD, Roy PS, Panda RM. 2016. Plant species richness pattern across India's longest longitudinal extent. Curr Sci. 111(7):1220-1225.
11. Conradi T, Temperton VM, Kollmann J. 2017. Beta diversity of plant species in human-transformed landscapes: Control of community assembly by regional productivity and historical connectivity. Perspect Plant Ecol. 24:1-10.
12. Treby DL, Castley JG. 2016. Determinants of microbat communities in urban forest remnants: a rapid landscape scale assessment. Urban Ecosyst. 2016(3):1-21.
13. Poelking EL, Schaefer CER, Fernandes Filho EI, de Andrade AM, Spielmann AA. 2015. Soil-landform-plant-community relationships of a periglacial landscape on Potter Peninsula, maritime Antarctica. Solid Earth 6(2):2261-2292.
14. Yan Y, Yu W, Zhang L. 2022. A method of band selection of remote sensing image based on clustering and intra-class index. Multimed Tools Appl. 81(16):22111-22128.
15. Choi HHSC, Sirakaya E. 2016. Measuring residents' attitude toward sustainable tourism: development of sustainable tourism attitude scale. J Travel Res. 43(4):380-394.
16. Xu X, Dong R, Li Z, Jiang Y, Genovese PV. 2024. Research on visual experience evaluation of fortress heritage landscape by integrating SBE–SD method and eye movement analysis. Herit Sci. 12(1):1-17.
17. Avolio ML, Koerner SE, La Pierre KJ, Wilcox KR, Wilson GWT, Smith MD, *et al*. 2015. Changes in plant community composition, not diversity, during a decade of nitrogen and phosphorus additions drive above-ground productivity in a tallgrass prairie. J Ecol. 102(6):1649-1660.