RESEARCH ARTICLE

Design and study on the landscape morphology of urban greenways from a low-carbon perspective: A case study of Fuzhou urban greenways

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Received: April 17, 2024; **accepted:** July 14, 2024.

With the acceleration of urbanization, the demand for a green living environment among urban residents is growing. Using Fuzhou urban greenways (Fuzhou, Fujian, China) as a case study, this research explored the landscape morphology design and research of urban greenways from a low-carbon perspective. With a survey of 200 visitors, Principal Component Analysis (PCA) and K-Means clustering algorithms were employed to identify the primary motivations for leisure among the respondents. The findings indicated that "proximity to nature" and "enjoying relaxation" were the two most significant factors, accounting for 21.89% and 13.92% of the total variance, respectively. K-Means clustering further categorized the visitors into four distinct groups, each exhibiting significant differences in their leisure motivations with F-values of 13.811, 69.382, 38.189, 64.291, respectively, and *P* values all less than 0.0001. The "proximity to nature" factor indicated a high need for nature closeness, while the "enjoying relaxation" factor suggested a preference for environments that offered relaxation and stress relief. This research explored the relationship between visitor behavior characteristics and greenway landscape design, and proposed design solutions to meet the needs of different visitor groups, which highlighted the necessity of incorporating visitor leisure motivations, behavioral traits, and satisfaction levels into urban greenway design to achieve multifunctionality and sustainability of the space. By emphasizing the importance of ecological preservation and cultural heritage in design, this research would promote the healthy development of urban green infrastructure, enhance residents' quality of life, and drive sustainable urban development.

Keywords: landscape morphology; low carbon; greenway landscape; tourist behavior; Fuzhou urban forest greenway.

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Introduction

The urban population is increasing with the continuous improvement of people's living standards. People's living space and production space for activities are also expanding, while people's requirements for the living environment are getting increasingly higher. Also, cities are actively constructing supporting infrastructure to create a more comfortable environment for urban residents [1]. Green space systems and activity facilities are also crucial considerations in cities. Although the green space system is constantly being upgraded and repaired, people have had difficulty feeling the natural ecological environment for a long time due to the scattered and relatively independent green space. People's high requirements for the environment have also caused subtle changes in the original green space system [2, 3]. The process of urbanization continues to accelerate. The appearance and pattern of Chinese cities have undergone significant changes, such as more "urban diseases," traffic congestion, air pollution, and other problems, making people more eager for orderly urban traffic and fresh air. The natural environment of the city is gradually deteriorating. Given the limited self-healing ability of the urban ecological environment, city managers need to take adequate measures to maintain the healthy development of the city and provide urban residents with a more comfortable and healthier green environment [4]. Against the backdrop of modern urban development, the development strategies for urban greenery are gradually shifting towards more comprehensive and systematic planning. Given the limited space in urban areas, effectively implementing greenery in compact city environments has become a significant research topic. Additionally, with the advancement of technology and changes in people's lifestyles, the functions of urban greenery are expanding beyond providing spaces for leisure and recreation. They now include ecological functions such as improving the urban climate, promoting biodiversity, and enhancing air quality. Therefore, the challenge in urban planning and environmental design is integrating urban greenery with modern technology to create aesthetically pleasing and ecologically valuable green spaces.

"Greenways" represents an eco-friendly urban development model that has gained widespread application and development in China. After the concept of "greenway" was introduced in China, relevant professionals widely accepted it according to location classification. The greenway in urban areas is called the urban greenway with the urban parks and squares being connected to residential areas to provide urban residents with green leisure and activity venues [5]. The greenway in the city's suburbs is called the suburban greenway, which mainly connects the urban and suburban areas, satisfying the close relaxation of urban residents [6]. The ecological greenway is in the countryside, which mainly relies on some natural resources or is used to improve the surrounding natural resources with the creation of unique natural landscapes. Many factors must be considered when building greenways including the urban building density, the complicated traffic, and the construction issues [7, 8]. The urban greenway facilitates the travel of urban residents, further improves the green environment of people's lives, and plays a vital role in enhancing the overall landscape of urban space. Residents and tourists evaluate city services based on their personal experiences, among that the greenway landscape space is a critical indicator of enhancing people's impression of the city and its comfort [9].

Many studies have explored urban greenway landscape design in recent years. Sun *et al*. suggested that urban green spaces could help alleviate the urban heat island effect, providing thermal comfort. The results showed that an elongated belt-shaped park in Beijing, China highlighted vital factors influencing the thermal comfort of the city with the tall forest trees positively impacting thermal comfort and ground hardening demonstrating a detrimental effect [10]. Keith *et al*. examined the use of urban greenways and found that the greenways significantly contributed to the city's sustainable development [11]. Kowarik studied the Berlin Green Belt with the focus on its social impact and found that greenways linked ecology, culture, and society, aiding communities in the design of reasonable urban green spaces. Furthermore, comprehensive planning in urban greenway design was necessary to strengthen the urban green infrastructure [12]. Jiang and Zhao analyzed the construction of county greenway networks and found that the greenway was established based on multiple needs including ecological protection, characteristic landscape, leisure, and entertainment. By using a gravity-resistance model, the relationships among primary elements were assessed to determine centrality, the ratio of supply, the demand of resources, and predicting the resource distribution and integration trend in the greenway construction [13]. In America, urban greenway landscapes were influenced by factors such as population density, regional accessibility, walkability index, and network density. Transportation and land-use planners played a significant role in shaping urban greenway landscapes, thereby raising the distinctions between the spatial form of urban greenway landscape and the built environment characteristics [14].

The determination of the most suitable type of greenway that can effectively cater to individuals' diverse needs while recognizing each variant's distinct characteristics is essential. Given the absence of a definitive criterion for such assessment, identifying the factors influencing the spatial design of urban greenways, understanding people's need for urban greenways, and evaluating tourists psychologically are necessary, which is pivotal for improving urban greenway landscape design and maximizing green spaces' functionality, consequently enhancing people's quality of life. Previous studies demonstrated the significant role of greenways in mitigating the urban heat island effect, improving thermal comfort, promoting ecological conservation, and enhancing social benefits. The current challenges in urban greenway design include addressing diverse demographic needs, achieving multifunctionality and sustainability of green spaces, and implementing ecological conservation and cultural heritage preservation within limited urban areas. These challenges necessitate innovative approaches and strategies in urban planning and environmental design. This research aimed to explore the design morphology of urban greenway landscapes, particularly from a low-carbon perspective and propose design solutions that catered to diverse population groups by analyzing visitor behavioral characteristics to enhance urban ecological environments and improve residents' quality of life. This study delved more deeply into the satisfaction levels of different demographic groups' leisure motivations concerning urban greenways, mainly focusing on the unique needs of elder people and children. Through applying Principal Component Analysis (PCA), a study of the internal relationships and laws of the data by calculating the variance contribution rate, eigenvalues, and load values of the data correlation matrix [15]. and K-Means clustering analysis, a simple iterative clustering that uses distance as a similarity index, this study explored the diversity of visitors' leisure motivations and analytically examined the spatial morphology design of greenways. Furthermore, the methodology developed by this study and the in-depth analysis of niche markets would provide new perspectives and empirical evidence for the personalized design and sustainable development of urban greenways.

Materials and methods

Principal component analysis

In the mathematical transformation, the total variance of the variable kept unchanged, so that the first variable had the most significant conflict, thereby becoming the first principal component. The variance value of the second variable was not correlated with the first variable, thereby becoming the second principal component. The rest variables were ranked in the same manner [16]. The objective empowerment process of the PCA method was shown in Figure 1. Data standardization was to unify the original data, while some original data was positive effect data, and some was harmful effect data. Therefore, homogenizing the data before use was necessary to ensure that the converted data could be analyzed in a unified manner [17]. The harmful effect data underwent a positive transformation, and the change was shown in Equation (1).

$$x_{ij} = -y_{ij} \tag{1}$$

where x_{ij} was the positive result value. y_{ij} was the original index value. The converting negative to positive values was primarily undertaken to ensure that all variables had the same weight in

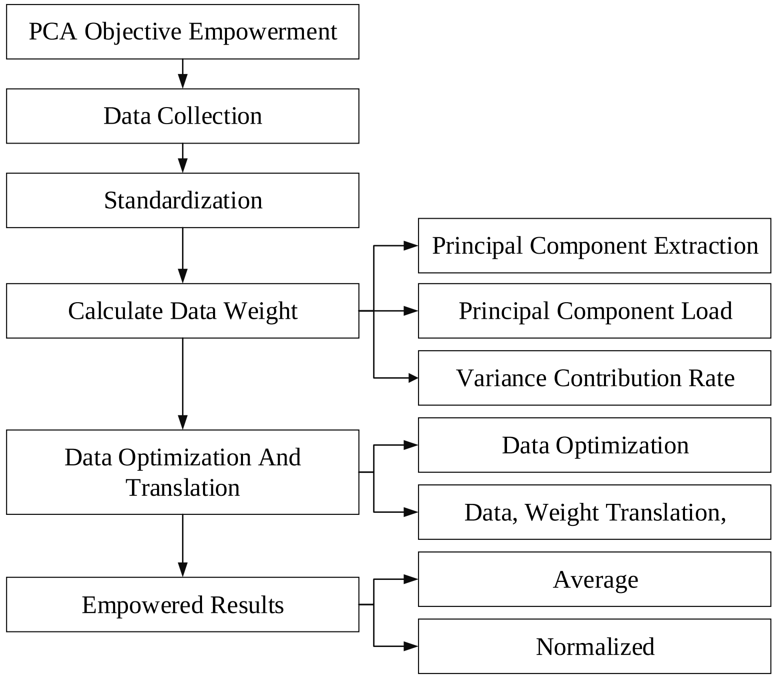

Figure 1. PCA objective empowerment process.

the analysis, avoiding biases that might arise due to differing scale magnitudes. The transformation of negative values to positive values in the study aimed to ensure that all data points fell within the positive range, facilitating practical mathematical computations in PCA. This transformation did not alter the relative order or trends of the data, which was solely to ensure mathematical consistency in data processing. According to the extracted principal component, data weights were calculated to obtain the feature root λ_m of the main element, the variance contribution rate e_m, the cumulative variance contribution rate *E*, and the gravel diagram of the factor eigenvalue arrangement. Then, according to the data analysis results, the load value x_{im} of the principal component was obtained. The variance contribution rate of data was then determined as follows.

$$p_i = \sum_{m=1}^{n} \frac{x_{im} * e_m}{\sqrt{\lambda_m} * E} \quad (2)$$

where p_i was the weight of the *i*-th data. In the data optimization and translation stage, retaining data items with a high variance contribution rate was necessary, thereby screening out items with more excellent value, which could represent most of the information in the original data. The data whose variance contribution rate was greater than 0 was retained, while the value less than 0 was eliminated to optimize the data.

K-means clustering algorithm

The data was divided into K classes, and the center of each class was derived from the mean of all the values in the class. The center of each class was represented by the cluster center [18, 19]. Given a data set X, the euclidean distance was used as a classification index and was expressed by Equation (3).

$$d = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2 + \dots + (x_n - y_n)^2} \quad (3)$$

The class center could be expressed by Equation (4).

$$z_j = \frac{1}{n_j} \sum_{x \in w_j} x \quad (4)$$

where n_j was the number of data of the same class. The error sum of squares was used as the objective function and shpwn in Equation (5).

$$J = \sum_{i=1}^{k} \sum_{j=1}^{n_j} d\left(x_j, z_i\right) \quad (5)$$

The algorithm process of K-means clustering included the selection of initial centers of k classes, finding the euclidean distance between any sample and the center in the N-th iteration before the selection being classified into the class with the shortest distance, applying the mean value method to update the center value of the class, and stopping the value updates until the objective function being converged, otherwise, the process returning to euclidean distance finding to continue the iteration.

Study location

The data used in this study was collected in Fuzhou city, the capital of Fujian Province, China located on the southeast coast of China between latitude 25°15' to 26°39' and longitude 118°08' to 120°31' with the Taiwan Strait to the east and is well known by rich historical and cultural heritage, advantageous geographical environment, and abundant natural resources. Surrounded by mountains, Fuzhou city features a distinctive river basin topography characterized by diverse terrains comprising mountains, hills, and plains with most of the area occupied by mountains and hills. Climatically, Fuzhou falls under a typical subtropical monsoon climate, known for its long summers, short winters, minimal frost, a favorable average annual temperature of approximately 19.7°C, an average annual precipitation of around 1,348.8 mm, and an average annual sunshine duration of 1,755.4 hours, which provide favorable circumstances for agriculture, hydroelectric power generation, wind power generation, and salt production. Fu Forest Trail in Fuzhou City was selected as the research target that connects many city parks and passes through many mountains with the combination of many scenic spots and natural resources, and therefore, meets the needs of urban residents in Fuzhou for a green environment. Moreover, it allows people to enjoy the natural scenery while relaxing, exercising, and visiting. The construction of residents' green travel and leisure facilities has continuously improved, attracting many tourists to Fuzhou [20-23]. From a low-carbon perspective, the Fu Forest Trail's design considers the minimal impact on the environment. The materials and construction methods employed in the trail aims at reducing interference with the natural ecology. As an exemplary urban greenway, the Fu Forest Trail showcases how urban ecological environments can be improved through green infrastructure, contributing to the city's low-carbon development, which enhances the city's ecological quality and improves residents' quality of life.

Data collection

Data was collected using questionnaires including the participant’s basic information, recreational motives, behavior characteristics, and satisfaction with the visited area. The basic information included gender, age, monthly income, education level, and occupation. Twenty recreational motives included feeling the natural environment, exercising, escaping from the noise, and seeking a comfortable environment. The five-point scale was used to obtain evaluation information for tourists. The scores of 1 - 5 represented very dissatisfied, dissatisfied, general, satisfied, and very satisfied. The behavioral characteristics of tourists encompassed various aspects such as travel period, frequency, companion, and activities. Tourists engaged in diverse behaviors at information collection places, which could be categorized into personal static behaviors (sitting and resting, reading, thinking), individual dynamic behaviors (walking, *in-situ* activities), and crowd behaviors (card playing, chatting). The study gauged visitor satisfaction with the Fu Forest Trail using a set of 10 evaluation criteria including the scenery en route, air quality, sanitation facilities, relevant signs, and guidelines. These criteria were assessed using a five-point scale, where scores ranging from 1 to 5 denoted varying levels of satisfaction as very dissatisfied, dissatisfied, general, satisfied, and very satisfied. According to the previous studies, the impact of urban environments on residents' health, well-being, and quality of life from three distinct perspectives including urban planning, smart city technologies, and air quality monitoring were explored [24-26]. In conjunction with previous studies, the assessment scale designed in this research aimed to comprehensively collect visitor satisfaction and environmental perception regarding Fuzhou's urban greenways. The field surveys and interviews of 200 randomly selected tourists were conducted from December 2018 to January 2019. The tourists themselves completed the questionnaires. 200 questionnaires were distributed, and 191 valid questionnaires were recovered. All procedures in this study was approved by the Ethics Committee of the School of Social and Public Administration, Lingnan Normal University (Zhanjiang, Guangdong, China) (Approval No. LNSG03). All participants were informed of the study's purpose, procedures, and data usage and signed informed consent forms. The questionnaire surveys were conducted at different places and periods along the Fu Forest Trail to ensure unbiased data, which included the entrance of the greenway, the critical nodes along the route, and the exit points to cover visitors during various time intervals. Additionally, data collection was performed daily during the survey period to avoid potential biases associated with collecting data only on weekends or specific dates.

Statistical analysis

SPSS (IBM, Armonk, New York, USA) was employed for the statistical analysis of this study. ANOVA was used to evaluate the differences of scores across various principal components among different clustering groups with *P* value less than 0.05 as significant difference and *P* value less than 0.01 as very significant difference.

Results and discussion

Basic Information of visitors

The visitors‘ basic information contributed to a better understanding of different demographic groups' leisure motivations and behavioral characteristics to provide more targeted recommendations for designing urban greenways and meet the diverse needs of various visitor groups. The results showed that there were slight differences in the male-to-female ratio. Tourists under ten and over 60 years old accounted for a relatively large proportion. The majority groups were within the income range of ¥2,000 – 5,000, accounting for 40.3% followed by those with a monthly income of more than ¥7,000. Tourists with a bachelor's degree accounted for a relatively large proportion, while the other academic degrees accounted for a reasonably even proportion. Many tourists were from national enterprises and institutions, students, and retired people, which might be related to their income, fixed holidays, and time to travel (Table 1).

Analysis of tourists' recreational motives

The recreational motives were classified into seven categories including getting close to nature, enjoying relaxation, exploring new things, maintaining health, entertainment, personal hobbies, and communication. The factor loads and eigenvalues of the various content of recreational motives were further analyzed based on the classification of leisure motivations and their corresponding PCA results (Table 2). Each leisure motivation category corresponded to a principal component. Under each principal component, specific contents were assigned their respective factor loadings, which represented each content's weights or influence levels on the corresponding principal component. Eigenvalues and the percentage of explained variance for each category were critical in the overall leisure motivations. Each factor loading represented the importance of specific leisure content to the corresponding principal component, while eigenvalues and the percentage of explained variance revealed the

Table 1. The tourists' basic information.

Attributes	Content	Number of people	Proportion
Gender	Male	95	49.7%
	Female	96	50.3%
Age (years old)	< 10	42	22.0%
	10 - 18	21	11.0%
	18 - 25	31	16.2%
	25 - 45	39	20.4%
	45 - 60	11	5.8%
	> 60	47	24.6%
Monthly income (¥)	< 2,000	33	17.3%
	2,000 - 5,000	77	40.3%
	5,000 – 7,000	32	16.8%
	> 7,000	49	25.7%
Education level	Below junior high school	25	13.1%
	High school/technical secondary school/junior college	31	16.2%
	Bachelor’s degree	100	52.4%
	Master's degree and above	35	18.3%
Occupation	Personnel of national enterprises and institutions	54	28.3%
	Individual merchants	11	5.8%
	Workers and peasants	13	6.8%
	Students	51	26.7%
	Freelance	18	9.4%
	Retired people	42	22.0%
	Other	2	1.0%

relative importance of overall leisure motivation categories. The K-Means clustering algorithm was used to categorize visitors based on their leisure motivations. Each cluster represented a group of visitors with similar leisure motivations. The principal factor was the key influencing factors extracted through PCA, reflecting different dimensions of visitors' leisure motivations. The scores of each cluster on the corresponding principal component were then determined, which assisted in analyzing the characteristics of each cluster (Table 3). There were significant differences among clusters in terms of the "proximity to nature" factor with cluster 3 scoring the highest of 0.7765 and cluster 2 scoring the lowest of -0.5147, respectively, indicating a stronger inclination of cluster 3 towards seeking experiences close to nature. For "enjoying relaxation," cluster 4 scored the highest of 0.8311, while cluster 2 scored the lowest of -0.7162. The results highlighted cluster 4's preference for leisure activities focused on relaxation and stress relief. In terms of "exploring new things," cluster 2 scored the highest of 0.4397, whereas cluster 3 scored the lowest of -0.5698, suggesting that cluster 2 might be more inclined to engage in new activities and experiences. For "maintaining health," cluster 1 scored 0.7965, which was significantly higher than that in other groups, indicating a greater focus on health and fitness-related activities. For factor of "entertainment", cluster 3 scored the highest of 0.7141, while cluster 2 scored the lowest of -0.5492, indicating cluster 3's preference for recreational and leisure activities. Regarding "personal interests," clusters 1 and 2 scored relatively low, whereas cluster 3 scored a negative value of -0.8972, suggesting diverse needs and preferences among groups regarding personal hobbies. Lastly, regarding "social interaction", cluster 4 scored the lowest of -0.7821, while clusters 1 and 2 scored higher. These findings suggested that cluster 4 might prioritize less social interaction during leisure

Table 2. Classification of recreational motives.

Recreational motives	Contents	Factor loads	Eigenvalues	Explained variance (%)
Getting close to nature	1. Feeling nature	0.821	4.813	21.892
	3. Breathing fresh air	0.781		
	6. Appreciating the natural landscape	0.779		
	13. Getting close to and understanding nature	0.779		
Enjoying relaxation	2. Relaxation	0.833	2.898	13.916
	5. Relieving stress	0.795		
	9. Getting away from the noise	0.685		
	11. Finding a comfortable environment	0.687		
Exploring new things	4. Making new friends	0.671	1.981	8.896
	7. Revisiting the old place	0.686		
	10. Exploring new landscapes	0.799		
Maintaining health	8. Exercise	0.942	1.501	7.162
	12. Healthy walk	0.911		
Entertainment	14. Killing time	0.838	1.311	6.324
	17. Enjoying freedom	0.577		
	18. Eliminating loneliness	0.597		
Personal hobbies	15. Experiencing different things	0.821	1.109	5.165
	19. Finding new attractions	0.798		
	20. Acquiring knowledge	0.644		
Communication	16. Improving relationship with family	0.791	1.071	5.018

Table 3. Clustering results.

Principal factor	Cluster 1 (67)	Cluster 2 (43)	Cluster 3 (35)	Cluster 4 (46)	F value	Significance
Getting close to nature	-0.0651	-0.5147	0.7765	0.2198	13.811	0.000
Enjoying relaxation	0.0166	-0.7162	-1.1141	0.8311	69.382	0.000
Exploring new things	-0.4987	0.4397	-0.5698	0.5576	38.189	0.000
Maintaining health	0.7965	-0.6892	-0.5313	-0.4032	64.291	0.000
Entertainment	-0.2241	-0.5492	0.7141	0.3458	18.133	0.000
Personal hobbies	0.1187	0.0671	-0.8972	0.0076	8.111	0.000
Communication	0.1204	0.4182	-0.7253	-0.7821	13.019	0.000

activities. The data suggested that the K-means clustering algorithm had successfully grouped visitors into distinct clusters with different leisure motivation characteristics.

Analysis of behavior characteristics

A notable trend emerged where most individuals chose public transportation for traveling, particularly during the hours before 9 a.m. and after 2 pm (Figure 2). The combined data of older people and children accounted for a more significant proportion of the individual dynamic behaviors. Children, known for their active and playful nature, were accompanied by older people whose environmental needs differed from the younger age groups. The elderly experienced a decline in physiological functions with age, leading to reduced mobility and sensory capabilities, thereby increasing their susceptibility to accidents. Moreover, as they underwent physical changes and shifted in societal roles, feelings of loneliness might

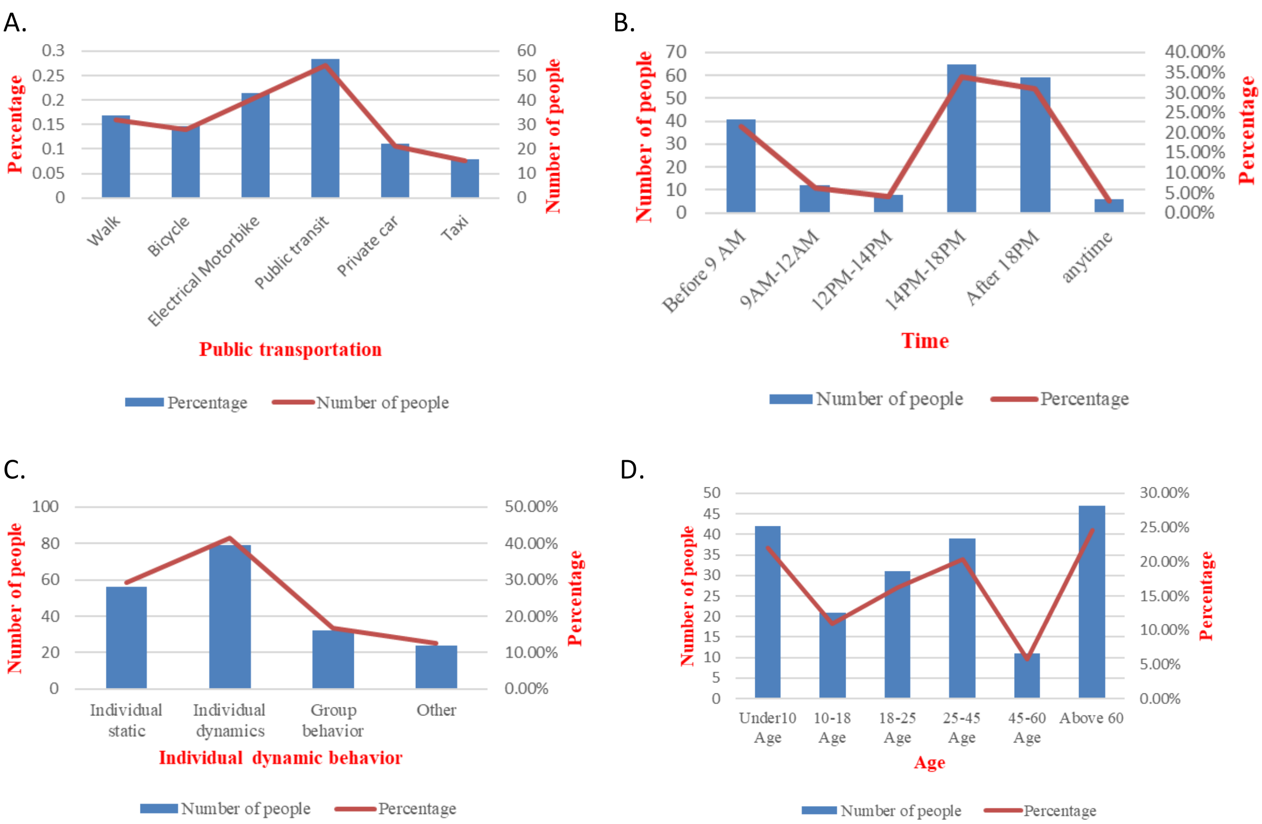

Figure 2. Tourist behavior characteristics.

emerge, often accompanied by decreased curiosity and security. In green spaces, older people sought areas with ample room and convenient amenities to facilitate relaxation and enjoyment of nature. When children were in contact with natural ecology, their enthusiasm for play could be stimulated, fully mobilizing their enthusiasm and subjective initiative. They could explore more new things in the game. Children needed a rich game environment in the process of playing, which could allow them to perceive more external things through the perception parts of the body, which encouraged them to feel different things and made them curious about superficial things. The older people and children demonstrated higher requirements for the urban landscape. Also, the relationship between older people and children was relatively close, which also impacted spatial planning and design more. The venues for older people and children were inherently related. Therefore, when considering the needs of particular groups of people, the behavior and habits of older people and children should be comprehensively evaluated when designing the spatial form of urban greenway landscapes. Furthermore, a landscape that conformed to older people's and children's behavioral psychology should be designed to facilitate their simultaneous travel. Landscape design principles prioritizing expansive visibility and appropriate spatial boundaries should be adopted to ensure children's safety without affecting other people's use.

Satisfaction analysis of the visited area

The analysis of the satisfaction of older people and children with the greenway landscape design of Fu Forest Trail revealed different concerns about the greenway landscape. The load factor results of the satisfaction indicated that older people in the greenway landscape prioritized various elements such as scenic views, ecological

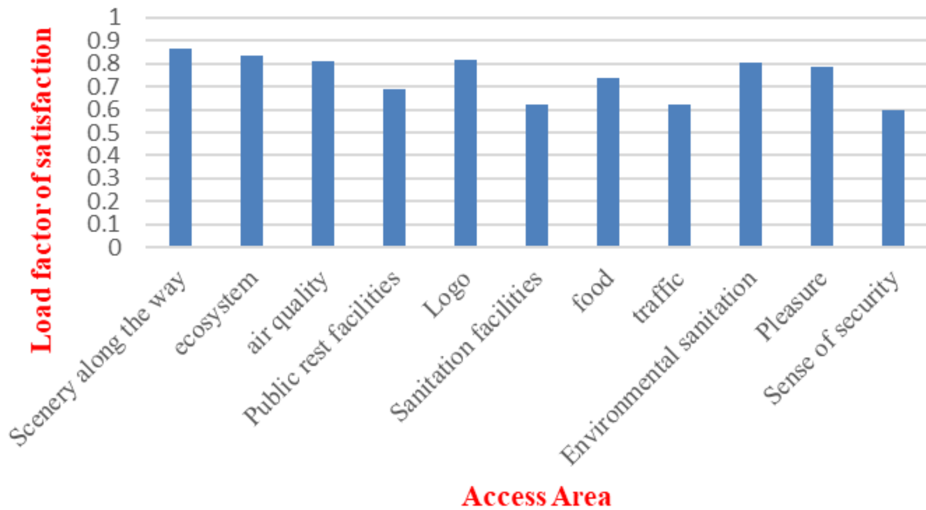

Figure 3. Load factor analysis.

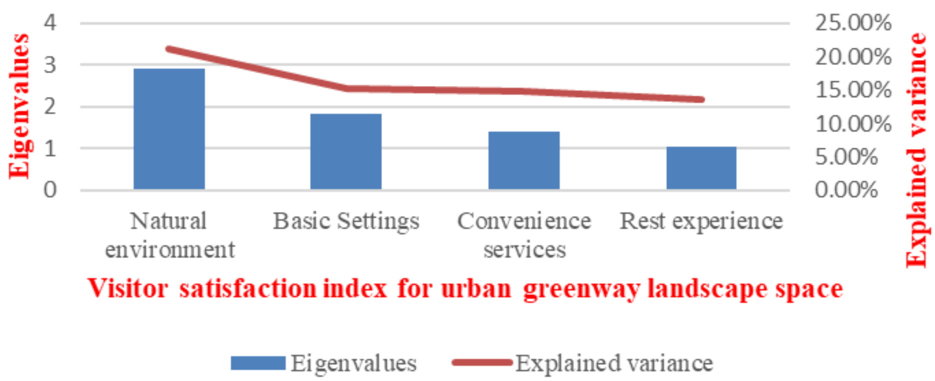

Figure 4. Principal factor analysis of satisfaction.

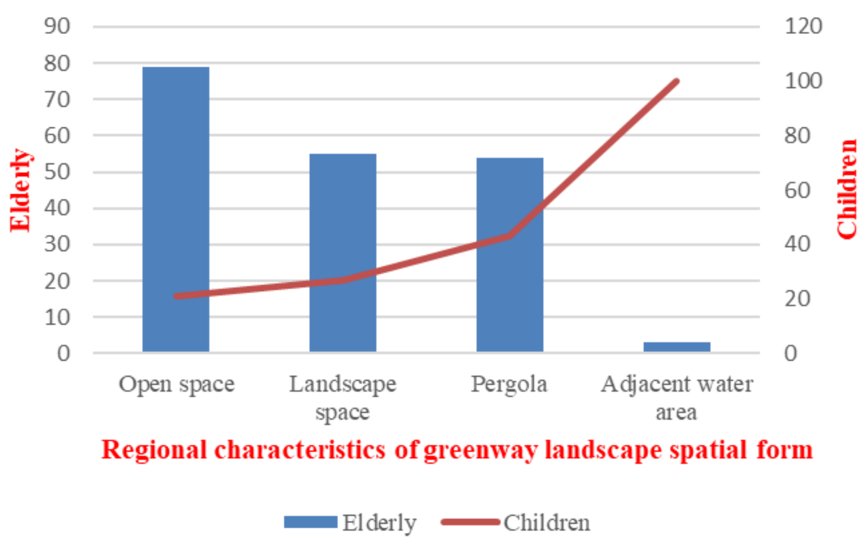

Figure 5. Needs for landscape space.

surroundings, air quality, public rest facilities, transparent sign interpretation systems, well-designed landscape, security measures, and a sense of enjoyment (Figure 3). After categorizing these options, the corresponding principal factor eigenvalues and explained variance were derived. The results showed that the data from questionnaires distributed among older people and children demonstrated the high overall satisfaction with Fu Forest Trail, particularly noteworthy, their heightened appreciation of the air quality. The elderly demographic desires increased opportunities to connect with nature and enjoy fresh air. The natural environment encompassed scenery along the way, ecological environment, and air quality. The basic settings included public rest areas and sign guidelines. Convenience services included environmental sanitation settings, food, and convenient transportation. The experience mainly included environmental sanitation, pleasure, and a sense of security. Fu Forest Trail capitalized on its distinctive geographical features to establish itself as a natural oxygen sanctuary. The copious trees and elevated terrain contributed to the air quality along the trail. Free from heavy industrial pollution and a few cases of artificial destruction, the vegetation thrived in diversity. The presence of various birds added to the allure, allowing visitors to immerse in nature and indulge in visual enjoyment. In the design of the greenway landscape, various regional elements such as open spaces, landscape features, pergolas, and adjacent water areas were incorporated based on regional attributes. The depicted satisfaction levels shown in Figure 5 suggested that older individuals preferred open space, landscape elements, and pergolas within the greenway landscape. Conversely, children demonstrated a heightened interest in water features and recreational zones.

Discussion

In exploring the landscape morphology design of urban greenways, the geographical characteristics of Fuzhou integrates natural landscapes, historical context, and modern urban development and has resulted in a unique urban landscape. Fuzhou's greenways serve as ecological infrastructure for the city and as vital links connecting historical culture and natural scenery, which enhance the urban ecological environment and enrich the leisure lives of its residents, winding through the city's mountains and waters. From a low-carbon perspective, Fuzhou's urban greenways incorporate numerous sustainable measures in the design including optimizing path planning, minimizing interference with the natural environment, and utilizing eco-friendly materials. These measures contribute to reducing urban carbon emissions and promoting ecological balance. The design of Fuzhou's urban greenways considers the local topography, climate, and ecology, striving to enhance the urban ecosystem while providing citizens with comfortable, aesthetically pleasing, and practical leisure spaces. This study used PCA to reduce data dimensions and highlight critical variables by simplifying the complexity of the dataset through extracting its main components. The specific process involved calculating the covariance matrix of the data, extracting eigenvalues and eigenvectors, and then selecting principal components based on the size of the eigenvalues. These principal components represented the directions of maximum variability in the data, aiding in revealing the relative importance of different leisure motivations. By using PCA, the study could effectively analyze the critical factors in visitor leisure motivations, providing a scientific basis for greenway design. K-Means clustering analysis was also applied to categorize visitors into different groups based on their leisure motivations. Through iterative calculation, the data points were assigned to K clusters to minimize the distance between data points within each cluster and its centroid. This study analyzed the characteristics of each cluster to reveal the features and needs of different user groups. The resulted information helped design greenways that aligned with users' preferences, increasing greenway usage and citizen satisfaction.

Further, a combination of PCA and K-Means clustering analysis and additional analytical approaches was introduced in this study to establish research methods. The standardizing collected leisure motivation data ensured comparability among variables in PCA. Subsequently, utilizing PCA for dimensionality reduction highlighted critical components in the data. Based on PCA results, suitable dimensions were chosen as input variables for K-means clustering. The determined optimal number of clusters (K value) were used to divide visitors into different groups during clustering. The incorporated machine learning method such as the random forest algorithm was used to explore the relationship between visitor leisure motivations and greenway usage more deeply. Through the combination of these methods, it offered a more comprehensive perspective and enhanced the understanding of visitor behavior patterns, providing more precise data support for the efficient design of urban greenways. The design of urban greenway landscapes under a low-carbon framework can benefit significantly from analyzing tourists' behavioral characteristics. By aligning the urban greenway design with urban development and local characteristics while leveraging the natural landscape, a focus on meeting users' diverse needs emerged, particularly those from older people and children who sought opportunities for exercise, recreation, and social interaction. Accordingly, incorporating fitness equipment, parent-child stairs, and seats were essential considerations in the greenway's design. The inclusion of curved seating catered to the conversational preferences of older individuals, while the provision of parent-child stairs addressed children's play and rest requirements [27, 28]. By integrating fitness amenities and cultural activities, the design could effectively cater to the simultaneous behavior and psychological needs of older individuals and children. Furthermore, the design should consider the interrelationship between older individuals' resting behaviors and the activities of accompanying children. Therefore, setting up play and rest areas in the greenway landscape met children's entertainment needs and ensured that older visitors had comfortable rest places [29, 30]. The primary purpose for older people to take children to travel was to get closer to nature and enjoy the fresh air in the ecological environment. However, older people's and children's behaviors were quite different in the pergola space. While older people wanted to take pictures while resting, children did not [31, 32]. Most older adults needed a quiet and comfortable environment for reading, resting, or chatting with a high degree of gathering. Therefore, arc design was often used to meet the needs of conversation. The green rate in this area was relatively high, which could create a certain degree of privacy for older people. It could meet the psychological needs of older people to a certain extent, but it could not meet the behavioral needs of children [33, 34]. Elderly individuals necessitated rest and communication, whereas children required spaces for amusement. Consequently, when conceptualizing the design of greenway landscapes, the behavior characteristics of older people and children must be considered. By integrating the existing landscape space features, the greenway could effectively cater to the specific travel requirements of these demographics. It enabled the greenway to have urban characteristics while meeting the travel needs of older people and children. Both older adults and children sought out landscape spaces that were accessible, welcoming, and open. Notably, children benefited from greenway landscapes with a general sense of openness, moderate hydrophilicity, and excellent accessibility. This research delved into the satisfaction levels of different visitor groups' leisure motivations on urban greenways by combining PCA and K-means clustering analysis. Through PCA, visitors' leisure motivations were categorized into several groups with "close to nature" and "enjoy relaxation" being identified as the most significant factors. K-means clustering analysis revealed the diversity of visitor groups regarding leisure motivations with substantial differences in greenway preferences observed among visitors of different ages and backgrounds.

This study enriched the theory and practice of urban greenway design and provided urban planners with more accurate data support, enhancing urban greenways' social, ecological, and economic benefits. The application and prospects of this research had significant implications in real life. Understanding the needs, leisure motivations, and satisfaction of visitors could provide recommendations for the spatial design of green landscapes. Particularly for specific demographic groups, their requirements for landscape spaces varied, and these considerations should be considered during the design process to meet the diverse needs of more residents and tourists. However, this study did not analyze the design of the landscape itself. In the future, a more in-depth analysis of the impact of behavioral characteristics on landscape design should make practical designs more ecological and human centric. By gaining a profound understanding of visitor behavioral characteristics, cities could better plan and design spaces for green transportation, providing an improved travel experience. Understanding visitor preferences and needs enabled the targeted provision of more convenient transportation facilities and services, encouraging more people to choose environmentally friendly transportation methods. This study provided a new perspective on the diversified design of urban greenways. By incorporating machine learning algorithms, the study deeply explored the complex relationship between visitor leisure motivations and greenway usage rates, offering a scientific basis for achieving efficient utilization and sustainable development of urban greenways.

Acknowledgements

This research was funded by the Ministry of Education Humanities and Social Sciences Youth Project (Grant No. 23YJC630235), Guangdong Province Philosophy and Social Sciences Planning Volunteer Service Research Special Project (Grant No. GD23ZYF13), Guangdong Provincial Ordinary University Characteristic Innovation Project (Grant No. 2023WCSCX060), and General Programs of Humanities and Social Sciences in Lingnan Normal University (Grant No. WT2212).

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