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Leveraging Big Data and Machine Learning for Smart Park Management

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***Abstract*—**The evaluation of ecosystem services is becoming increasingly important in urban research, yet its performance assessment remains to be explored. The Importance-Performance Analysis (IPA) provides a new perspective for the evaluation of ecosystem services. Recently, big data has provided higher data volume and dimensions for urban research, but the evaluation of ecosystem services based on big data still needs to be explored. This study takes the parks in Shanghai, China as an example, and explores the perceived evaluation of ecosystem services based on big data and machine learning. The study also uses Importance-Performance Analysis (IPA) to evaluate the optimization priorities of ecosystem services, and proposes corresponding resource allocation optimization strategies. Our study found that the overall satisfaction rating of various ecosystem services in the park is high, while their importance rating is low. Using both as park renewal indicators would lead to different optimization priorities. The IPA method can guide the optimization priorities of park ecosystem services. The ecosystem service that requires the highest priority optimization is Social interaction and recreational activities. This study provides methodological insights for ecosystem service assessment and other related urban research, which is of practical significance for achieving human well-being.

Keywords—urban park, ecosystem services, Importance - Performance Analysis, big data, smart cities, machine learning

I. INTRODUCTION

Rapid urbanization has brought an unprecedented crisis of environmental and social sustainability to cities. As plots of land that provide ecological resources as well as recreational spaces for the public, urban parks are crucial to the sustainable development of cities [1], and therefore also assume important social responsibilities and public service services. Although rapid urbanization has strained land within cities, public demand for urban recreational spaces, especially urban parks, continues to increase [2]. With the contradiction of land resource scarcity and rising demand from residents, how to achieve effective management and planning of land resources in the urban renewal process is crucial for the sustainable development of future cities.

Park ecosystem services play a vital role in enhancing human well-being and quality of life. By linking ecosystem services to human well-being, we can gain insights into social preferences and better understand the relevance and potential trade-offs in land planning and management decisions [3]. In the context of urban land planning, urban parks are often considered as green infrastructure strategies for sustainable urban development, aiming to provide various ecosystem services [4]. Moreover, the concept of ecosystem services has been used as a framework to assess the benefits that urban areas offer to local residents [5]. Ecosystem services encompass the goods and functions provided by ecosystems, which are essential for human survival and quality of life. Urban parks, with their extensive green spaces, serve as valuable habitats for flora and fauna, showcasing the beauty of the natural landscape while also exerting a significant influence on the local microclimate. However, there is still a need for a comprehensive understanding and in-depth evaluation of the ecosystem service functions provided by parks.

Research on park ecosystem services based on big data is still to be explored. With the rapid pace of urbanization and the increasing need for urban renewal, there is a growing interest in smart urban planning as a means to address various urban development challenges and enhance the quality of life for urban residents. Machine learning, serving as a crucial technology within the realm of artificial intelligence, has played a pivotal role in urban block planning and renewal. The proliferation of big data has further facilitated the rapid advancement of machine learning techniques tailored specifically for handling large datasets, thus becoming a prominent research area [6]. Artificial intelligence and machine learning systems have reached a level of maturity where they can be effectively employed for information retrieval and processing on various internet platforms [7]. In previous studies, conventional survey methods such as sampling, questionnaire distribution, and semi-structured interviews were primarily utilized. However, these traditional approaches demand substantial human and material resources for questionnaire design, implementation, and subsequent data recovery and transcription. Additionally, these methods often entail significant time investments. To overcome these limitations, the utilization of big data and machine learning techniques presents a valuable opportunity to significantly reduce the human, financial, and temporal costs associated with data collection and analysis, thereby enhancing the efficiency and effectiveness of research endeavors.

This study uses big data and machine learning methods to collect and centralize the evaluations of citizens after visiting urban parks in the popular review website. The importance of each ecosystem service function of urban parks and the citizens' demand for them are understood through the importance-performance analysis method. This research aims to answer these research question: 1) What is the current status of ecosystem services provided by urban parks to the public? 2) Which ecosystem services in urban parks need to be prioritized for improvement in the context of urban renewal? Methodologically, this study relies on big data and machine learning for urban park service evaluation, and this research method system provides some implications for perception evaluation studies of urban parks and other types of spaces. In practice, the results can help regional

government authorities, urban planners, and park managers to better understand which aspects are most important for sustainable development of urban parks, and where parks need more attention and improvement now.

II. METHOLOGY

A. *Importance and satisfaction evaluation based on machine learning*

This study employs an innovative approach that harnesses supervised machine learning to convert online reviews into quantifiable satisfaction and importance ratings for park ecosystem services. Within the study, four modules were incorporated, amalgamating key technical methods such as machine learning, keyword matching, and statistical analysis.

Module One: Data Pre-processing.

This study utilizes data from Dianping (http://www.dianping.com), one of the largest online-to-offline (O2O) platforms in China, which enables the public to provide ratings and reviews for attractions and businesses. As of 2020, the platform boasted an impressive user base of over 250 million monthly active users and hosted more than 150 million reviews. To collect the necessary data, a Python web crawler was employed, enabling the extraction of review data from October 2015 to December 2020. In the end, the study identified 59 parks with over 200 reviews each, accumulating a total of more than 100,000 data entries.

The unstructured text within databases undergoes processes like data cleaning, tokenization, and vectorization to become structured. Initial steps involve de-duplication of data and elimination of blank reviews. Given the potential of non-formal content like emoticons and web links in reviews to interfere with subsequent data processes and satisfaction model training, regular expressions are used to remove web links and emoticons without sentiment expression. Emoticons containing sentiment expression are standardized and incorporated into an upcoming sentiment dictionary. Next, text is tokenized based on semantic partitions using Jieba, recognized for its speed, efficiency, and accuracy during large-scale text processing.

To enhance tokenization accuracy, renowned Chinese sentiment dictionaries, including NTUSD and Dalian University of Technology sentiment dictionary, were consolidated, appended with internet slang and emotion-expressive colloquialisms [8][9]. The curated sentiment dictionary is loaded into Jieba's custom dictionary. Following tokenization, and before text vectorization, meaningless stop words are removed. The final list of stop words was collated from Harbin Institute of Technology, Baidu, and Sichuan University, with sentiment words, conjunctions, negatives, and degree adverbs (from the CNKI dictionary) excluded. Post-Jieba tokenization, these stop words are filtered out in preparation for text vectorization.

The process of text vectorization is paramount in text information processing. Traditional methods include the One-hot model, Bag-of-Words, and TF-IDF models [10]. However, these conventional word representation models have limitations like oversized vector dimensions and inadequate text representation in many contexts. In this study, the word2vec model is adopted for training to vectorize each word in the database, which subsequently represents sentences, serving as inputs for machine learning. The word2vec model consists of the Continuous Bag of Word and Skip-Gram models. The former predicts the word at the current position based on context, whereas the latter predicts the context for a given word. Finally, low-dimensional word vectors are produced. This approach offers several advantages over traditional methods, such as reduced vector dimensions, fixed vector size, low computational costs, and enhanced representation of word similarities.

Module Two: Ecosystem Service Dictionary.

This encompasses the construction of a Chinese ecosystem service dictionary that enables indexing, searching, and rapid identification of ecosystem services in social media data. Literature reviews [11][12] revealed that urban park participants in China often emphasize nine ecosystem services. With this foundation, this study proposes an indicator system for the evaluation of urban park ecosystem services. A seed word expansion approach was employed to establish an exhaustive ecosystem service lexicon.

Leveraging Shanghai's public park text data and through techniques like tokenization, part-of-speech tagging, and frequency statistics (top 500 nouns), an ecosystem service seed lexicon was extracted. Simultaneously, CNKI was used for "park" keyword searches to augment the seed lexicon. The seed words, when fed through Dalian University of Technology's synonym forest, generated synonymous words which, after manual filtering, were categorized into nine ecosystem service categories. To ensure lexicon comprehensiveness and improve ecosystem service word recognition accuracy, the word2vec trained word vectors were used to calculate cosine similarities with seed words, incorporating semantically proximate words into the lexicon. This similarity calculation iteratively accumulated five times, with a threshold set at 0.95. The final ecosystem service keyword lexicon was curated through manual revisions.

A random sample of 500 data entries was manually annotated to identify ecosystem services, comparing the differences between keyword matching and manual annotation results. Four metrics: recall, precision, F1 score, and accuracy were utilized to gauge the reliability of the ecosystem service identification method, which combined the ecosystem service dictionary with keyword matching. All metrics for the nine ecosystem service categories exceed 0.9, demonstrating the practical applicability and efficacy of the constructed ecosystem service lexicon.

Module Three: Automatic Satisfaction Scoring Model Based on Machine Learning.

This module can autonomously assess the satisfaction present within spontaneously uploaded text and contrasts the performance difference between this model and existing ones. A random selection of 4500 reviews was used as machine learning data. Data labeling was jointly undertaken by two experts. In cases where discrepancies arose during the labeling process, discussions were initiated to reconcile differences and attain a consistent value, ensuring standardization in data annotation and the scientific nature of the machine learning training. The expert-labeled data, after further verification, was split into training and test sets, with the former accounting for 80% and the latter 20%. Most sentiment analyses based on machine learning construct one or more classifiers for sentiment satisfaction modeling; however, they often neglect the progressive relationship

between different satisfaction levels, treating them as entirely independent. To address this and enhance model accuracy, this study employed a regression approach based on the XGBoost algorithm for satisfaction modeling and prediction.

XGBoost is an optimized distributed gradient boosting algorithm designed for efficient execution of machine learning tasks and flexible algorithm deployment. It introduces optimizations under the Gradient Boosting framework. XGBoost offers parallel tree boosting technology (also known as GBDT, GBM), resolving many data science problems based on machine learning with enhanced accuracy in a short duration. It outperforms traditional gradient boosting algorithms in both model fitting time and predictive performance, also demonstrating superior results on unseen datasets. Hence, in this research, the xgboost library, written in Python and based on this algorithm, was employed for relevant machine learning tasks. Given the advantages of the regression approach mentioned earlier, the XGBRegressor model based on the XGBoost algorithm was used for data feature learning and fitting.

The model evaluation process was twofold: it included a stand-alone random test with a confusion matrix and a control experiment to further assess the model's performance. The standalone random test used the test set (900 data points) to draft a confusion matrix comparing the real expert-assigned scores with the scores predicted by the ML-based method. Comparative experiments utilized three popular Chinese sentiment analysis tools: Baidu AI Natural Language Processing Sentiment Analysis Tool, ROST CM6 (Wuhan University ROST), and SnowNLP, along with the XGBClassifier based on the XBG algorithm, totaling four methods. Using these tools, the test dataset was scored for satisfaction, with a 5-fold cross-validation repeated five times. Each repetition calculated performance metrics for the four comparative methods and the method proposed in this study. Cross-validation is a model validation technique for evaluating the model's predictive capabilities on entirely new datasets, thereby mitigating overfitting and selection bias issues. After the 5-fold cross-validation, evaluation metrics were computed, including the Spearman rank correlation coefficient (ρ), R2, Mean Absolute Error (MAE), and Mean Squared Error (MSE).

Table 1. Mean and Standard Deviation of Each Metric under 5-Fold Cross-Validation for Different Models

Models		SnowNLP	ROST CM6	Baidu NLP	XGBclassifier	This Study
Spearman Correlation Coefficient	Mean	0.59	0.63	0.75	0.72	0.77
	Standard Deviation	0.01	0.01	0.01	0.01	0.00
R^2	Mean	0.57	0.18	0.00	0.48	0.58
	Standard Deviation	0.07	0.02	0.06	0.03	0.01
MAE	Mean	1.75	1.20	1.38	0.87	0.83
	Standard Deviation	0.04	0.02	0.04	0.01	0.00
MSE	Mean	4.93	2.58	3.13	1.63	1.32
	Standard Deviation	0.20	0.07	0.13	0.08	0.01

Module Four: Application and Analysis.

Leveraging the applied model and associated computations, three distinct variable sets were derived: i) overall satisfaction concerning the park, ii) perceived frequency of various ecosystem services, and iii) satisfaction levels associated with these perceptions.

B. Park evaluation based on Importance-performance analysis (IPA)

The Importance-Performance Analysis (IPA) methodology, initially developed as a decision-making tool in the marketing sector, facilitates the evaluation of user satisfaction across various attributes and informs the creation of strategic management measures to enhance user experience [13]. This technique has found extensive application across a range of sectors, proving its versatility and efficacy, including in the fields of tourism and healthcare. The IPA framework, as shown in Figure 2, enables the classification of park ecosystem services into four distinct quadrants based on their importance and satisfaction levels. Excellence Zone (Q1) represents attributes or services that are highly important to park users and also highly satisfactory. These elements are considered strengths of the park and should be maintained at their current high performance levels. In Maintenance Zone (Q2) quadrant, attributes or services are deemed less important by users but still result in high satisfaction. While not a top priority, these elements should be consistently maintained to ensure continued satisfaction among visitors. Neglect Zone (Q3) includes attributes or services that are considered less important by park users and also yield low satisfaction. While immediate improvements may not be necessary, long-term strategies should address these areas to enhance overall satisfaction. Improvement Zone (Q4) consists of attributes or services that are highly important to park users but deliver low satisfaction. These elements require immediate attention and improvement to bridge the gap between expectations and reality and enhance visitor experience. This signifies a pressing need for improvement and should be the primary focus of park managers to enhance visitor experience.

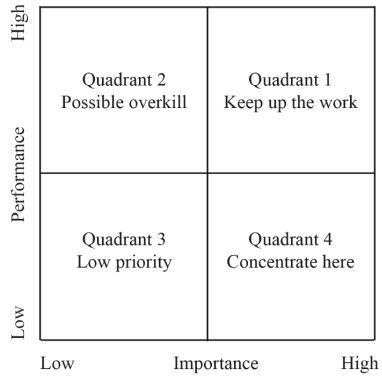

Fig. 1. Importance-Performance analysis four quadrant plot

III. RESLUTS

A. Evaluation of park services based on big data

The user's perception assessment of the ecosystem can be found in Figure 4. For the satisfaction of ecosystem

services, users were overall more satisfied, with all ecosystem services scoring above 0.6, with an average score of 0.73, making the overall ecosystem services of the park better. Users were most satisfied with aesthetic appreciation (0.75), physical and mental restoration (0.74) and environmental improvement (0.72), and least satisfied with religious values (0.61) and educational services (0.62).

The importance of ecosystem services varied significantly across service sub-items, but most scores were less than 0.5, with park recreation (0.78) being the most important part of ecosystem services, scoring much higher than the rest of the sub-items. Social interaction (0.58), aesthetic appreciation (0.42), environmental improvement (0.41), physical and mental restoration (0.31) and biodiversity (0.30) were relatively more important, while historical and cultural (0.10), educational services (0.03) and religious values (0.02) were the least important.

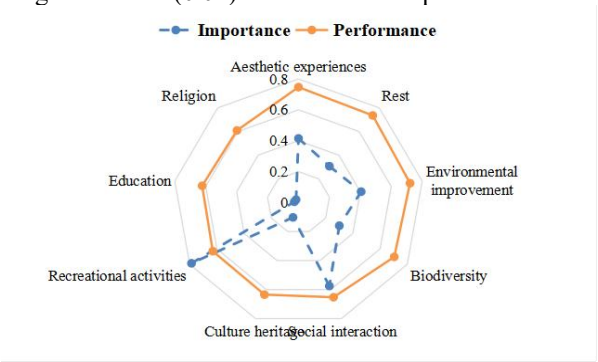

Fig.2 . Ecosystem service evaluation.

B. Importance - Performance Analysis of Park Ecosystem Services

The Figure 3 shows the distribution of importance-performance analysis points of park visitors to nine sub-items of ecosystem services. Among them, aesthetic appreciation and environmental improvement are located in the first quadrant (Keep up the good work). This indicates that these two ecosystem service subcomponents are highly important and perform well from the visitor's perspective, and are widely recognized and satisfied. In particular, the score of aesthetic appreciation is significantly higher, which shows that Shanghai River Park has obtained good results in the pre-park landscape planning.

Users' physical and psychological restoration and biodiversity are located in the second quadrant (Possible overkill). It indicates that in this park, the performance of these two subscales is above importance and in the supply redundancy stage. Physical and mental relaxation, the most basic efficacy of outdoor activities, did not receive special attention from visitors. Also, visitors pay relatively little attention to satisfying biodiversity when visiting a park with a forest park theme.

History and culture, education and religion are located in the third quadrant (Low priority). This quadrant is a weak area of supply and demand for forest park ecosystem services. Shanghai, as a representative of fast-paced city, people more often choose indoor systematic understanding of history and culture and education, so it is difficult for urban parks as outdoor recreational green space to become a place for real knowledge acquisition. Moreover, Chinese religious activities often have specific sites, such as Buddhist and Taoist temples. It is difficult for urban parks to be recognized by the public as formal religious places.

Social interaction and recreational activities are located in the fourth quadrant (Concentrate here). This result surfaces that the supply of urban parks in these two sub-items is inadequate to meet the needs of visitors. The public is eager for parks to provide them with a place to socialize, promote interpersonal interaction, and achieve social integration. It is evident that the zoning of recreational blocks in the Shanghai River Park is inadequately planned and recreational facilities are lacking. The sustainable development of the park requires a focused renewal of these two services.

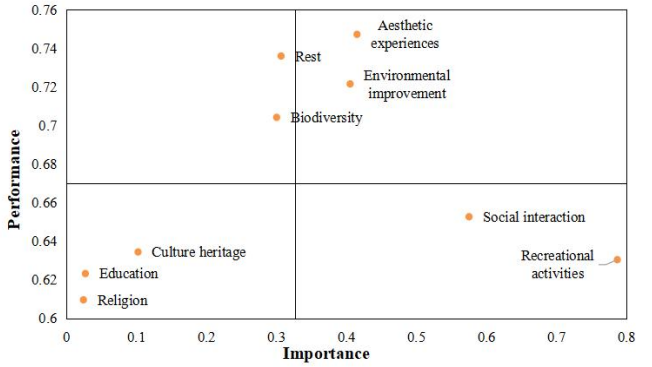

Fig. 3. IPA results for ecosystem services.

IV. Discussion

This paper presents a new methodological framework for assessing the perception of urban park ecosystem services, based on text review data from emerging social media platforms. Compared with traditional questionnaire survey methods, this approach boasts advantages such as objectivity, comprehensiveness, and effectiveness. Moreover, our study particularly used the subjective evaluation framework of park users as the analytical vehicle for the perception of ecosystem services. The method is simple, easy to generalize, and efficient in processing large amounts of data. The challenge of quantitatively evaluating the diversity of ecosystem service values has always posed significant time and cost issues to researchers. In our study, we demonstrate the advantages of utilizing social media data to address this challenge. This paper not only confirms that unstructured and voluntary social media data may become an important information source for evaluating urban park ecosystem services, but it can also directly provide feedback to decision-makers of urban parks based on the evaluation results. This is crucial for further improving the planning, design, and management of urban parks in the future.

Voluntary comment text from social media data is beneficial for precisely characterizing user evaluations. Many studies have highlighted the importance of quantifying public perceptions of ecosystem services in balancing nature and society. In this respect, social media data is a valuable source of information about today's conceptualization of information sharing and the cultural creation process relative to the natural environment [14], such as the Weibo tags we often use, reviews from the public, and so on. Sharing personal opinions and pictures on social media platforms reflects the collective values of society, helping researchers understand the shared image

cognition of people towards the ecosystem, and is powerful evidence of the continuous existence or extinction of ecosystem services. At the same time, the openness of social media platforms may also encourage people to construct the same values in different ways [15]. For example, on the Dianping platform analyzed in this paper, people are happy to share their views, partly because their shares can guide others and promote the unity of values. At the same time, traditional surveys are also favored by many researchers when evaluating ecosystem services. Researchers use statistical analysis of the data source population to illustrate the fairness and scientific nature of the evaluation process, such as gender, social class, age or residence, etc. As social media platforms become more and more popular, free expression breaks through the limitations of traditional respondents, providing a place for people of different social classes to express their feelings. At the same time, traditional surveys also have a strong guiding nature. For example, when being asked about the purpose of going to the park, respondents may pay more attention to purposeful options, and services that subtly happen like mental relaxation may be ignored. The social media data selected in this paper comes from users' direct experiences and firsthand feedback, making the descriptions and depictions of park visits more detailed.

This research advocates for a non-linear, multidimensional understanding of ecosystem services through the lens of an enhanced IPA method. This pioneering approach transcends the constraints of single attribute analysis, enabling a more discerning and holistic view of park features and ecosystem services that need improvement, despite the inherent challenges in distinguishing these critical areas through traditional performance or importance evaluations. A noteworthy advantage of this method is its categorization of various park elements and ecosystem services into four distinct quadrants, thus elucidating different priority levels for actionable enhancements. This segmentation is instrumental in streamlining the decision-making process for park management, thereby assisting planners in judiciously allocating resources to foster a park environment that resonates well with its visitors. Furthermore, extant IPA research predominantly relies on small-scale studies, such as questionnaire surveys, which have inherent limitations in terms of case studies and sample sizes, thus constraining the scale and depth of the data obtained. Prior studies have indicated the potential of big data to expand our comprehension of user feedback. Through the employment of web crawling techniques and machine learning in our research, we were able to rapidly gather numerous comprehensive reviews from park users over several years. This data acquisition approach enabled us to understand user perceptions in the context of both park elements and ecosystem services, thereby facilitating a more profound comprehension of rational park planning strategies.

This findings identified social interaction and recreational activities as the most vital ecosystem services needing enhancement. This highlights an urgent call for park managers to invest more resources in reinforcing these services. For instance, creating more communal spaces such as seating areas and rest zones, building interactive installations such as playgrounds and game zones, and initiating community events like concerts, craft fairs, or fitness classes could foster a more engaging social environment. These strategies not only elevate recreational opportunities but also cultivate a sense of community, enabling parks to serve as vibrant social hubs within urban settings. By responding to these insights, park managers can ensure that urban parks continue to deliver essential ecosystem services effectively, thereby enhancing the quality of urban life and promoting the sustainable development of urban environments. Through such efforts, parks can evolve from mere recreational spots to active social catalysts, fostering community engagement, promoting health and well-being, and preserving biodiversity within urban landscapes.

Leveraging the insights from the enhanced Importance-Performance Analysis (IPA) offers a nuanced strategy roadmap for park authorities, guiding them toward nurturing areas identified as emerging strengths while proactively mitigating potential risks. Firstly, for the Emerging Strengths type which highlights Environmental Improvement and Aesthetic Experiences, it is suggested to amplify visitor performance through sustained efforts and investments, which could include the establishment of educational programs that spotlight the environmental endeavors initiated in the park and fostering art installations to enhance aesthetic appreciation. Secondly, the Potential Risks quadrant, representing Recreational Activities and Social Interaction, implores urgent interventions to address the falling performance levels; reviving these critical areas could encompass hosting community events and devising interactive zones that facilitate vibrant social interactions. Thirdly, for the Overcompensation type including Biodiversity and Physical and mental health, a strategic reassessment is vital to harmonize the resource allocation, bringing it in line with the actual relevance of these aspects, potentially redirecting resources to nurture emerging strengths and address potential risks, thereby promoting balanced development. Lastly, the Declining Attention type which incorporates cultural heritage, Education, and Religion, necessitates a meticulous appraisal to determine the future course — revitalization or a calibrated reduction in focus, possibly utilizing technology to foster immersive historical or cultural experiences, reviving the relevance of these elements. Implementing these suggestions would facilitate a harmonious evolution of park spaces, dynamically aligning with visitor preferences and steering towards a vibrant, sustainable, and resonantly harmonious park environment, ensuring an enriched visitor experience through a thoughtful balance of enhancement and conservation strategies.

V. Conclusion

This research examines the perceived evaluation of park ecosystem services in Shanghai, China, using big data and machine learning. It also utilizes the IPA method to evaluate the optimization priorities of ecosystem services, and provides corresponding resource allocation optimization strategies. Our study found that the park's overall satisfaction rating of ecosystem services is high, while their importance rating is low. This means that using both as indicators for park renewal would lead to different optimization priorities. The IPA method can guide the

optimization priorities of park ecosystem services, where social interaction and recreational activities are the ecosystem service that requires the highest priority optimization. This study provides methodological support for the assessment and renewal of public places and services, as well as valuable methodological insights for ecosystem service assessment and other urban research, which is essential for achieving human well-being.

For future research, more of this study should be done using big data and machine learning to obtain reviews of visitors on the popular review website, making the target group of the study limited. Since the website is mostly used by young and strong adults, even though children and the elderly are the main audience groups of urban parks, the evaluations collected in this study are mostly the feelings of young and strong adults or their relaying or subjective assumptions about the feelings of children and elderly visitors. Given that different age groups have different needs for park ecosystem service functions, future research could look for more efficient information collection and analysis models from the perspective of children and the elderly.

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