Landscape Performance Related Factor Correlations in Small Public Spaces: Structural Modeling Applied to Nanjing Subway Entrances

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Abstract: Landscape performance is an important topic in contemporary landscape architecture. The renewal of small-scale public spaces has a positive effect on community vitality and the sustainable development of landscape resources. To improve the quality of small-scale public spaces, a clear understanding of landscape performance and its correlative factors is necessary. The structural equation model (SEM) provides a way of objectively evaluating the influence of public space on landscape performance, which could be useful in the design decision-making process. This study develops a methodological framework that implements SEM to assess landscape performance and provides a case study of typical small-scale public spaces represented by subway entrances in Nanjing. Five latent factors and 11 observed factors were selected to construct a landscape performance assessment model. Various methods, including investigation, image recognition, and modeling, are exploited to analyze the characteristics of the subway entrances quantitatively. An SEM-based calculation is conducted to obtain the correlation coefficient of latent factors and the explanatory degree of observed factors. Statistical analysis indicates that the green space and traffic capacity affect the landscape performance of the subway station entrances. Moreover, the fluctuation of any latent factor may cause the decay or enhancement of related factors. Therefore, we suggest that design strategies for subway station entrances should balance traffic, visibility, plants, and facilities. More importantly, this study works as a technical support and reference point for future empirical research to obtain an in-depth understanding of the ideal landscape construction forms in small-scale public spaces making it possible to predict the level of landscape performance when a new study area is given.

Keywords: Landscape performance, Structural Equation Model (SEM), correlative analysis, small-scale public space

1 Introduction

Contemporary landscape architecture research has gradually shifted from the intuitive perception and empiricism of traditional research to the scientific research and judgment of quantitative analysis. Moreover, many researches focus on the sustainable utilization and renewal of urban public landscape resources (BROWN & CORRY 2011). Increasing attention has been paid to the scientific cognition and quantitative assessment of landscape renewal and the transformation of small-scale public spaces. Therefore, landscape architecture must address the challenges of urbanization and improve the technology of design decision making (PATTACINI 2021).

An urban subway station entrance is a typical example of a small-scale public space. It maintains coordination with urban public spaces and provides a generous landscape experience for residents. However, the landscape potential of small-scale public spaces has been critically ignored in previous constructions. Many small-scale public spaces are isolated, restrained, and pedestrian-unfriendly due to the lack of overall design and planning (DOULET et al. 2017). It is important to scientifically analyze the landscape composition forms of small-

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scale public spaces to propose universal design principles and strategies for landscape renewal.

Landscape performance is a measure of the effectiveness of landscape practices in achieving the expected objectives under the premise of sustainable development (LUO et al. 2021). Previous studies have focused on the selection of performance evaluation factors and measurement methods and the description and comparison of these factors. However, some of these factors are theoretically abstract. Few studies have systematically and objectively covered the construction mechanism of landscape space. In factor analysis, structural simplification of these latent factors is an indispensable procedure for solving estimation problems.

As an effective multivariate statistical method, the structural equation model (SEM) can measure factors that cannot be directly observed by transforming them into observable factors and can verify the path loading between latent factors and observed factors by harnessing a covariance matrix (LIVOTE & WYKA 2009). Traditional methods, such as the analytic hierarchy process, fuzzy comprehensive evaluation, and entropy weight method, suffer from over-reliance on expert opinions and low accuracy of the factor weight calculation. Compared to these traditional methods, a factor weight calculation based on SEM is more accurate because it can calculate the factor structure and factor relationship at the same time. Moreover, an indicator is allowed to be affected by one or more factors. In addition, this approach improves model production efficiency by providing a verifiable theoretical framework and graphical model (HUANG et al. 2021).

Therefore, to address the aforementioned challenges, we propose a novel approach to achieving the quantitative evaluation of landscape performance in small-scale public spaces. We utilize multi-source data to extract the features of public spaces and evaluate the influence of the observed and unobserved factors on landscape performance using SEM. The urban subway station entrances of Nanjing are selected as a research case. The results, including recognizing the importance of correlative factors and proposing design strategies for subway station entrances, provide technical support and a reference point for the renovation of similar small-scale public spaces, such as streets, pocket gardens, and public squares.

2 Methods

This study proposes a method for assessing landscape performance based on SEM. It can analyze the weight of each factor related to landscape performance of small-scale public spaces in a quantifiable way and can reveal the relationship among latent factors. The methodology used consists of four steps (Fig. 1): (1) establishing the theoretical model, (2) data collection, (3) parameter estimation, and (4) correlation analysis.

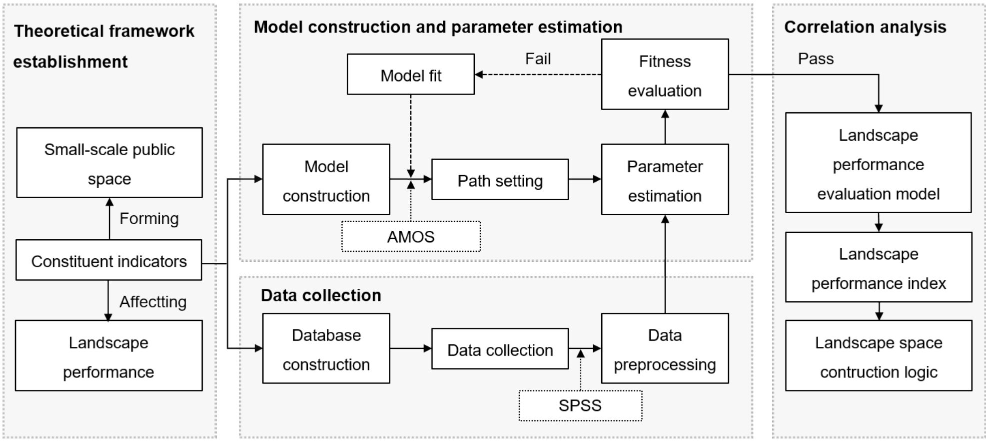


Fig. 1: Steps for constructing a landscape performance assessment model

2.1 Establish the Theoretical Framework

Through the literature review and the physical properties of subway entrance, the influencing factors on the landscape performance can be summarized into two categories: space character and construction factor. Specifically, traffic capacity is the main function of subway entrance, and visual openness reflects the spatial form of subway entrance. They jointly illustrate the organizational relationship of the landscape space (AZIZ 2020). Greening and facilities, as the physical components of subway entrances (CATHERINE et al. 2013, PESCHARDT & STIGSDOTTER 2013), mainly reflect the service capability.

Next, these latent factors were subdivided into ten observation factors. As shown in Figure 2, the observed and latent factors are represented by rectangular and circular boxes, respectively. The "dependency" relationship between factors is represented by a one-way arrow. This model is the basis for all subsequent data analysis. The meanings and measurement methods of each observation factor are shown in Table 1.

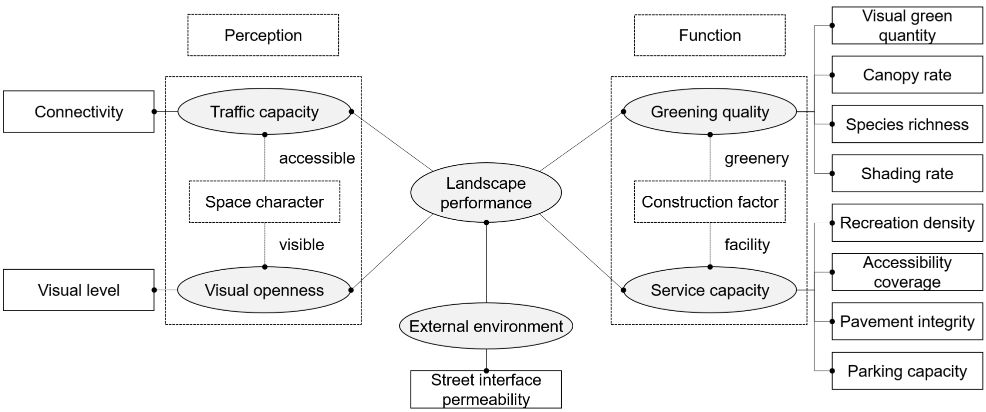


Fig. 2: Theoretical hypotheses of landscape performance

Table 1: Factors of landscape performance assessment model

Factor	Indicator	Qualitative explanation	Calculation formula	Quantitative explanation
Traffic capacity	Connectivity (LIU et al. 2015)	The degree of connection among different paths. Pedestrians usually enter a space with higher connectivity.	$X_1 = \frac{1}{RAA}$	RAA is the global depth of the axis model.
Visual openness	Visual level (TURNER et al. 2001)	The visual conditions. The higher the visual level, the easier the space is to be observed and perceived.	$X_2 = \sum_{n=1} \mathrm{V(q)}$	n is the total number of grids. V(q) is the visibility region of the grids that are visible from q.
Greening quality	Visual green quantity	The average level of green quantity perceived by visitors.	$X_3 = \frac{\sum_{n}^{i=1} \frac{P_g}{P_t}}{n}$	n is the total number of panoramas, P_g is the number of green pixels, and P_t is the total number of pixels.
	Canopy rate	The average level of canopy structure in the walking environment of subway station entrances.	$X_4 = \frac{\sum_{n}^{i=1} \frac{S_g}{S_t}}{n}$	S_g is the number of green space pixels in the i-th photo, and S_t is the total number of pixels.
	Species richness (MAGURRAN 2004)	The richness of plant species on the site.	$X_5 = \frac{S_p}{\ln A}$	S_p represents number of plant species and A is its area where field survey conducted.
	Shading rate	The shading capacity of plants, indicating the ability of trees to provide a comfortable environment.	$X_6 = \frac{S_{ts}}{S_w}$	S_{ts} is the vertical projection area of trees in the pedestrian space, and S_w is the total area of the pedestrian space.
Service capacity	Recreation density	The ratio of the number of seats to the site area.	$X_7 = \frac{N_s}{A}$	N_s is the number of seats, and A is the sample area.
	Accessibility coverage	The matching degree between barrier-free facilities available and required.	$X_8 = \frac{N_b}{S_r}$	N_b represents the quantity of barrier-free facilities, and S_r is the quantity required.
	Pavement integrity	The pavement quality of pedestrian space.	$X_9 = \frac{O_t - F_t}{O_t}$	O_t is the total area of paving space, and F_t is the area of pavement defects.
	Parking capacity	The ratio of the number of non-motorized parking facilities to the site area.	$X_{10} = \frac{S_{\mathrm{nmv}}}{A}$	S_{nmv} is the non-motorized parking area, and A represents the total area of the site.
External environment	Street interface permeability	The spatial recognition of the entrance environment from the street interface.	$X_{11} = \frac{\sum_{n}^{t=1} a_i t}{S}$	t is the penetration of interface i, a is the area of interface i, and S is the total vertical interface area.

Note that landscape performance exists as a "high-order factor" in the model, which can fully express the relationship between the first-order factors, namely, the four latent factors. Thus, it is assumed that all observation factors can be combined into a total score for landscape performance. In the process of data analysis, a hierarchical and structural evaluation model is established on the basis of measuring real environmental data, objective weighting, and structural characteristics of factors. As a result, it can reflect the operational logic of landscape performance in a subway entrance.

2.2 Data Collection and Preparation

Considering the construction situation of the existing subway entrances in Nanjing, we selected 131 entrances as survey samples, such as, Gulou subway station and Jimingsi subway station (Fig. 3). The data collection methods can be classified into three categories: mapping data based on computer-assisted auditing, environmental data based on image recognition, and environmental audits based on field investigations (Fig. 4).

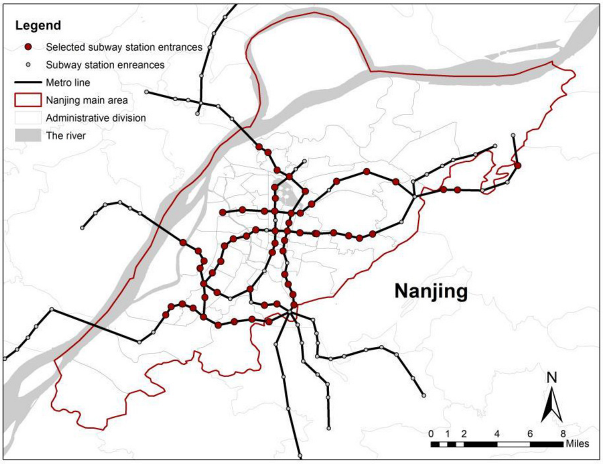


Fig. 3: Sample distribution of subway station entrances in Nanjing

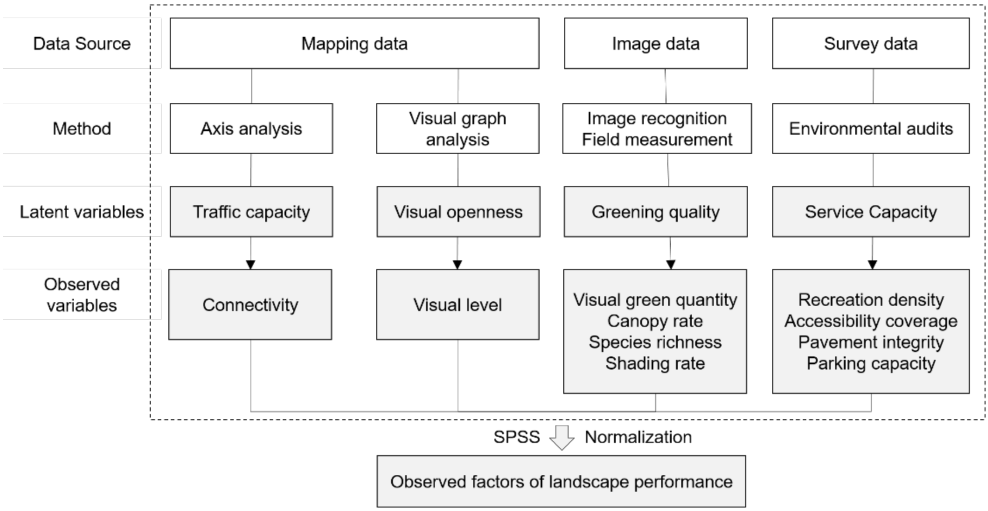


Fig. 4: Methods for data collection

(1) Traffic capacity

The observed factors of “traffic capacity” and “visual openness” are connectivity and visibility level, respectively, both of which reflect the spatial organization efficiency of subway station entrances. Space syntax is an important tool for simulating the structure and function of space. It is exploited to reflect the features and trends of walking behavior (HILLIER & HANSON 1984). Therefore, we harnessed Depthmap to build an axis model to obtain the average connectivity data (Fig. 5).

(2) Visual openness

The acquisition of visibility was achieved in a similar way to that of the previous factor. The invisible occlusion area and landscape elements obstructing the view, such as wind pavilions and plants, are defined. Then, Depthmap is used to obtain a visibility graph (Fig. 6).

Fig. 5: Results for traffic capacity (Entrance 3 of Gulou Station)

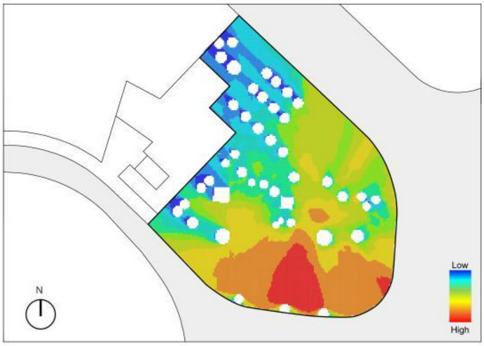
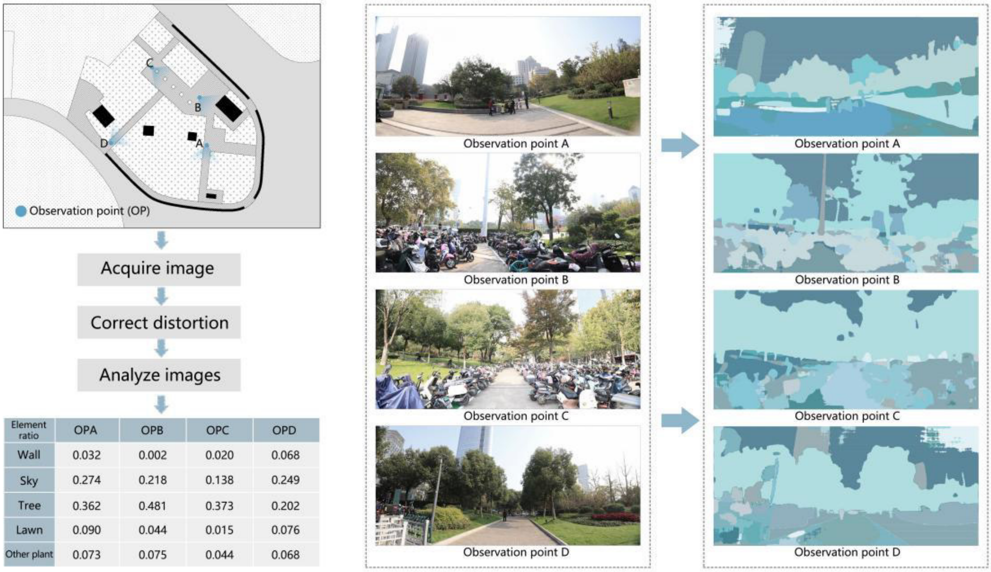


Fig. 6: Results for visual openness (Entrance 3 of Gulou Station)

(3) Greening quality

The latent factor “greening quality” is composed of four observed factors. Data collection for these factors relies on photography and measurement. The photographic equipment includes a SLR camera, wide-angle lens, and fish-eye lens. First, a panoramic picture was shot using three observation points. A Canon wide-angle lens was used to simulate the visual field of the human eye. In the shooting process, the shooting position of the camera was set at the middle line of the road, and a visual height of 1.5 meters was taken as the benchmark for shooting.

After taking photos on the site, both the visual green quantity and canopy rate use semantic segmentation technology to determine the proportion of green space pixel values in each photo (Fig. 7). We used Photoshop to correct the distortion and semantic segmentation technology, that is, the SegNet recognition model (BADRINARAYANAN et al. 2017), to identify image composition. The pixel points in the pictures were identified as elements such as sky, road, buildings, and greening. Next, the percentage of pixel values of plant communities in each picture was calculated, and the visual green quantity data were obtained by calculating the average value of the observation points.



Element ratio	OPA	OPB	OPC	OPD
Wall	0.032	0.002	0.020	0.068
Sky	0.274	0.218	0.138	0.249
Tree	0.362	0.481	0.373	0.202
Lawn	0.090	0.044	0.015	0.076
Other plant	0.073	0.075	0.044	0.068

Fig. 7: The collection method of the visual green quantity (Entrance 3 of Gulou Station)

For the measurement of the canopy rate, three observation points in the path of pedestrians entering the subway station were selected, and a fish-eye camera with a 180° angle was used to shoot fish-eye images at a height of 1.5m from the observation point (Fig. 8). Image semantic segmentation was also carried out to calculate the proportion of tree crown pixels at each measurement point.

Fig. 8:
Results of canopy rates
(Entrance 3 of Gulou Station)

As for the measurement of variety richness, we counted plant varieties and measured the area volume of the sample. This index was calculated using the Gleason (1922) index. The shading rate of the walking space was obtained by calculating the ratio of the projected area of trees to the total area of pedestrian space.

(4) Service capacity

To measure the service capacity of landscape facilities, this study investigated the number and distribution of seat facilities, barrier-free facilities, and parking spaces by field investigation (Fig. 9). To measure the pavement integrity of the pedestrian space, the ratio of the well-preserved pavement area of the pedestrian space (excluding damage, cracks, warping, fracture, etc.) to the total pedestrian area was calculated.

(a) Seat facilities (b) Barrier-free facilities (c) Parking spaces

Fig. 9: Results of service capacity (Entrance 3 of Gulou Station)

2.3 Parameter Estimation and Fitness Evaluation

After collecting all samples, we imported the original data into the SPSS software for normalization to eliminate the influence of different dimensions. Then, 131 samples were randomly divided in half by SPSS for exploratory factor analysis and SEM analysis.

We imported the normalized data into SPSS 24.0 software for the exploratory factor analysis. Since traffic capacity and visual openness contain only a single observed variable, we assume that there is no unexplained measurement error in these two latent factors. Therefore, we focus on exploratory factor analysis among service capacity and greening quality, and their corresponding observed factors.

The results of the Kaiser-Meyer-Olkin test and the significance test (< 0.05) showed that the observed factors were correlated. As shown in Table 2, the component extraction results of "service capacity" and "greening quality" were consistent with the theoretical model. Since the coefficients were higher than 0.9 and the construct reliability result was acceptable, we regard the latent factors as interrelated with the corresponding observed factor group. Through exploratory factor analysis, the hierarchical relationship of the index system was preliminarily determined.

Table 2: Validity test of evaluation factors

Latent factor	Observed factor	Factor loading	Cronbach's α coefficient	Average variance extracted	Construct reliability
Service capacity	Recreation density	0.654	0.942	0.7682	0.9285
	Accessibility coverage	0.933			
	Pavement integrity	0.940			
	Parking capacity	0.944			
Greening quality	Species richness	0.754	0.918	0.6609	0.886
	Shading rate	0.844			
	Visual green quantity	0.785			
	Canopy rate	0.864			

Then, AMOS software was used to run SEM analysis to verify the index system. In the evaluation of absolute fit indices, the model passed the confirmatory analysis. Specifically, the CFI was 0.927, which meets the standard requirement that it should be greater than 0.9. The RMSEA was 0.075, which was slightly less than the critical value of 0.08. Among the relative fit indices, both the IFI and PNFI met the adaptation standard of 0.9.

The model fit results show that landscape performance was positively correlated with service capacity, greening quality, visual level, and connectivity to varying degrees. Following the path coefficient, the effect intensity of the observation factors on landscape performance was determined (Fig.10).

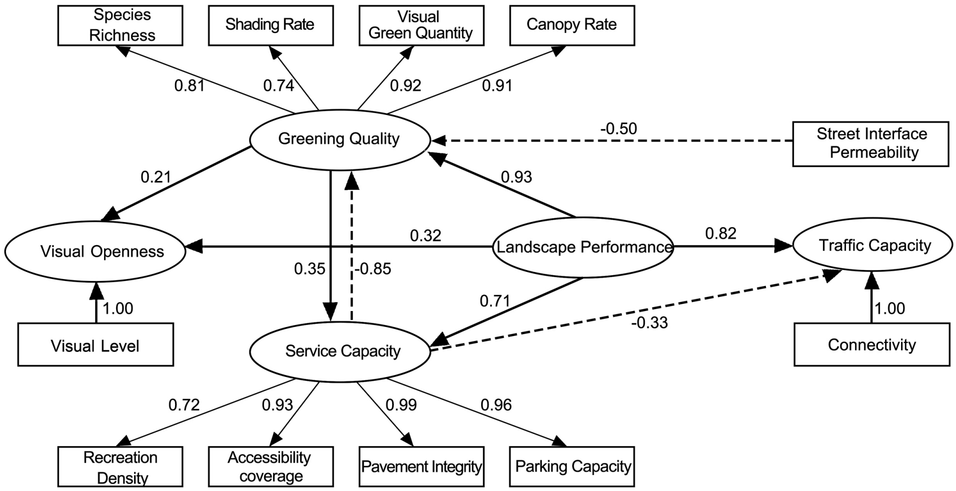


Fig. 10: Fit results of landscape performance assessment model

Finally, the path coefficient can be used for the weight of each factor to predict the level of landscape performance when a new study area is given. Furthermore, researchers can improve landscape performance and put forward targeted design strategies from the four dimensions of space, vision, green space, and facilities.

3 Results and Discussion

(1) Greening quality significantly affects landscape performance.

The model fit results show that the factors had a positive effect on landscape performance: greening quality (standard path coefficient 0.93), connectivity (standard path coefficient 0.82), and service capacity (standard path coefficient 0.71). This finding confirms the importance of greening quality and transportation in the landscape design of subway entrances. The visual level of plant communities is the most important influence on the landscape performance of subway entrances.

(2) Correlation among the latent factors of subway entrances

There is an interaction among the latent factors. When one landscape factor is weakened, other landscape factors may change accordingly. For example, traffic capacity had a negative effect on service capacity (path coefficient -0.33). The smaller the proportion of impassable areas (green space, non-motorized parking lot) in the landscape space, the more balanced the segmentation of the traffic path to the overall space. As a result, the better the connectivity of the entrance, the more ideal is the traffic capacity.

The permeability of the external observed variable along the street interface inhibits "greening quality" (path coefficient -0.50). This demonstrates that the main factors affecting the permeability of the subway entrance are not only the landscape conditions of the subway entrance itself but also the external urban spatial forms, such as road greening. This finding suggests that the relationship within the outer urban green space should be considered in the design of subway entrances.

(3) High-level interpretation of observed and associated latent factors

In the measurement model, the observed factors were able to comprehensively depict the latent factors. Visual green quantity (path coefficient 0.92) and canopy rate (path coefficient 0.91) had the largest contribution to the greening quality of the subway entrances. This result demonstrates that the three-dimensional green quantity indexes, namely, "visual green quantity" and "canopy rate," can better reflect the performance of the green space in subway entrances than a two-dimensional quantity index can.

The factors that dominated the service facilities were the pavement integrity of pedestrian spaces and the capacity of parking facilities. First, by investigating at subway entrances, we found that the high-frequency activities in the entrances were shown to be traffic and transferring, while the activity frequency of recreation behaviors were relatively low. This means that the rest facilities were not the main facilities. Second, the main activity scenes for users were the squares and roads, which reflects the importance of pavement integrity in subway entrances. Through the survey, it was found that the main way for people to arrive at a station was by walking or cycling, which gives rise to the high-density non-motorized parking demand. Therefore, improving pavement quality and parking design can promote traffic efficiency.

4 Conclusion and Outlook

In this work, we proposed a methodological framework that implemented SEM to analyze the correlation between landscape performance and four latent factors in small-scale public spaces. Using the path diagram in the SEM model, we developed a landscape performance evaluation system and discussed the design strategies of subway station entrances. With the support of multi-source sample data, we summarized the regular characteristics and formed an intuitive description of the landscape performance of subway station entrances in Nanjing.

In comparison with previous studies, this study offers improvements in three respects. First, it allows researchers to objectively measure the latent factors in small-scale public spaces by analyzing physical environment factors. Second, our use of SEM technology to avoid the subjective and descriptive defects of traditional performance evaluation provides a novel quantitative way for landscape performance research. Finally, our framework can be used to carry out retrospective analyses of landscape design and help designers identify design defects.

This study has certain limitations. Because the case study comprises subway station entrances in Nanjing, it cannot be guaranteed that the statistical results are generalizable to other small-scale public spaces. The factor sets of landscape performance still need to be expanded by adding indicators related to the behavior patterns of pedestrians. Notwithstanding its limitations, this study provides a scientific basis for proposing design strategies for small-scale public spaces, especially subway station entrances. Our ongoing work is to propose evaluation thresholds according to the data distribution to determine whether a design performs well or not, and to apply the results to more projects and to analyze more types of small-scale public spaces.

Applying digital technology in landscape performance research is an important symbol of contemporary development. To improve the landscape environment, researchers should adopt mathematical models with parameter systems, strengthen logical analysis, and improve estimation methods. This study provides an example and a basis for landscape performance evaluation using SEM. By applying our method to other small-scale public spaces, the analysis and measurement of the rules of landscape performance can be achieved. The study also provides strategies for landscape optimization design in small-scale public spaces.

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