Ecological and Perceptual Factors Shaping Age-Friendly Quality in Rural Public Spaces

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Abstract

As rural populations in China rapidly age, enhancing the age-friendliness of public spaces in these areas has become a crucial priority. This study examines the relationships between ecological experiences, spatial perception, and perceived quality in a rural village in Jinan, China. A mixed-methods design was adopted, integrating field behavioural observations with 176 questionnaire surveys. The data were analysed using PLS-SEM to evaluate the proposed structural relationships. The findings reveal that ecological experience positively influences and enhance overall spatial perception such as continuous greenery and shaded semi-open spaces were found to extend users' length of stay and foster greater social interaction.

Keywords: Age-friendly rural public space; Ecological experience; Spatial perception; PLS-SEM

1. Introduction

As the population ages in rural China, public spaces have become increasingly important in supporting older adults' daily lives, social participation, and psychological well-being (Buffel et al., 2012; Organization, 2007). The combination of youth outmigration and longer life expectancy has led to higher levels of aging in rural areas compared to urban regions. Consequently, the role of public spaces has shifted from primarily serving circulation functions to becoming key settings for social interaction, leisure, and emotional adjustment (Gehl, 2011). Previous research has mostly concentrated on barrier-free facilities and services (Lui et al., 2009; Wang et al. 2024a; Wang at al., 2024b), often overlooking the impact of ecological quality—such as continuous greenery, tree canopy shading, and microclimatic comfort—on participation and satisfaction through perceptual mechanisms (Bowler et al., 2010; Lin et al., 2010). Rooted in environmental-behaviour theory, the influence of the physical environment on behaviour is mediated by perceptual and cognitive

processes. Spatial perception plays a crucial role in the relationship between environmental attributes and behavioural outcomes, while perceived health benefits further shape one's overall evaluation of a space (Gifford, 2014; Mehrabian & Russell, 1974).

This study proposes a structural path model of "Ecological Experience – Spatial Perception – Perceived Health Effect – Overall Satisfaction" to assess how ecological optimization enhances age-friendliness through perceptual and health-cognition pathways. Using Dongquan Village in Jinan as a case study, we applied Partial Least Squares Structural Equation Modelling (PLS-SEM) to test the proposed relationships, complemented by behavioural observation for contextual validation, based on 176 valid questionnaires. This research empirically identifies the multi-path mechanisms through which ecological experiences influence the quality of age-friendliness, clarifies the mediating roles of spatial perception and perceived health effects, and establishes a dual-layer framework of "model testing – behaviour validation" to enhance contextual interpretability. The findings provide both theoretical and practical guidance for the ecological upgrading and age-friendly design of rural public spaces.

2. Literature Review

2.1 Research Progress on Age-Friendly Rural Public Spaces
With the advancement of the active aging agenda, developing age-friendly environments has become a central concern in planning and landscape design (Organization, 2007). Existing research primarily focuses on material and functional improvements—such as barrier-free facilities, pedestrian safety, and service provision—particularly emphasizing accessibility and diversity in urban settings (Lui et al., 2009; Gehl, 2011). In contrast, rural public spaces are integral to everyday life, blending production, social interaction, and neighbourhood attachment within networks based on familiarity (Wang et al., 2015). Although their social importance is recognized, studies mainly concentrate on facilities, with limited attention given to how ecological environmental quality influences participation and satisfaction through perceptual mechanisms. Therefore, a shift towards examining ecological quality and spatial perception processes in age-friendly rural public spaces is necessary.

2.2 Ecological Environmental Quality and Elderly Behaviour
Ecological environmental quality significantly influences outdoor comfort and spatial attractiveness (Bowler et al., 2010), with green coverage, tree canopy shading, and microclimatic regulation affecting older adults' activity frequency and length of stay (Lin et al., 2010). Restorative environment theory explains that natural elements promote satisfaction and stress reduction through mechanisms such as "being away," "fascination," and "compatibility," while greenery continuity and semi-open spaces enhance perceived safety and social engagement (Kaplan & Kaplan, 1989; Sugiyama et al., 2008). However, existing research remains largely correlational and lacks systematic examination of the structural links among ecological experience, spatial perception, and behavioural outcomes. In rural contexts, where ecological features are embedded in everyday life, structural path analysis is needed to clarify how ecological experience shapes public space use through perceptual and health cognition processes.

2.3 Environmental–Behaviour Perspective and Mediating Mechanisms
Environmental–behaviour theory posits that environmental influences on behaviour and attitudes operate through perceptual and cognitive processes (Mehrabian & Russell, 1974), with spatial perception—such as safety, accessibility, and comfort—acting as a key mediator between environmental stimuli and public space use (Gifford, 2014). Perceived health effects, reflecting subjective evaluations of physical and psychological benefits, further shape satisfaction and participation (Hartig et al., 2014). Despite the well-established "environment–perception–behaviour" framework, rural public space studies rarely apply structural equation modelling to test these mechanisms (Hair et al., 2019). Consequently, structural modelling is needed to clarify how ecological experience indirectly affects satisfaction through perceptual and health cognition processes.

3. Methodology

3.1 Study Area
Figure 1 shows Dongquan Village in the mountainous area of Jinan was selected as the case study due to its representative hilly landscape and well-defined node–path spatial structure, including a central square, waterfront nodes, main street, and transitional residential spaces. As rural aging increases, these areas serve as key venues for older adults' social and leisure activities. Distinct ecological features—such as spring-fed waterfronts, tree-lined streets, shading facilities, and continuous greenery—alongside a mix of traditional and renovated social spaces, provide an appropriate context to examine the structural pathway of "Ecological Experience–Spatial Perception–Perceived Health Effect–Overall Satisfaction," with behavioural observations enhancing explanatory validity.

(a)   (b)

Figure 1. Dongquan Village, on the other hand, is situated in the Caisi Sub-district of Liucheng District, Jinan City. This village has a history spanning over 700 years and is located at the intersection of 36°60' N latitude and 117°28' E longitude, with an approximate altitude of 150 metres, Distribution of village spatial resources (a), Aerial view of the village (b).

3.2 Theoretical Framework and Research Hypotheses

This study, guided by environmental-behaviour theory, develops a structural path model that links Ecological Experience (ECO), Spatial Perception (SPA), Perceived Health Effect (PHE), and Spatial Satisfaction (SPS) (Figure 2), to systematically examine how ecological experience affects age-friendly outcomes. The study proposes the following direct hypotheses: H1 (ECO → SPA), H2 (ECO → PHE), H3 (SPA → PHE), H4 (PHE → SPS), H5 (ECO → SPS), and H6 (SPA → SPS). In addition, mediating mechanisms are tested through H7 (SPA mediates the relationship between ECO and PHE), H8 (PHE mediates the relationship between ECO and SPS), and H9 (ECO indirectly influences SPS through the chain pathway SPA → PHE). Together, these hypotheses form a multi-path structural framework for analysing how ecological experience shapes the age-friendly quality of rural public spaces.
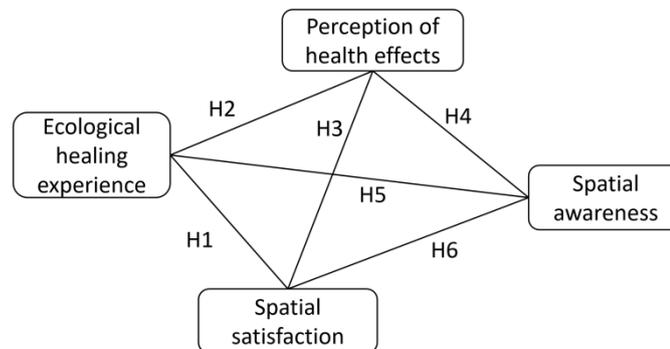

Figure 2. Theoretical framework diagram.

3.3 Questionnaire Design and Data Analysis

Measurement items were developed for four constructs—Ecological Experience (ECO), Spatial Perception (SPA), Perceived Health Effect (PHE), and Spatial Satisfaction (SPS)—using a five-point Likert scale. A total of 176 valid responses from residents aged 60 and above were obtained, with all constructs showing strong reliability (Cronbach's α > 0.80). Data were analysed using PLS-SEM, assessing measurement validity through factor loadings, composite reliability (CR), and average variance extracted (AVE), and evaluating structural relationships via path coefficients and R² values. Path significance and mediation effects were tested using 5,000-bootstrap resampling in SmartPLS.

3.4 Behavioural Observation for Contextual Validation

Systematic behavioural observations and mapping were conducted across peak daily periods to record older adults' activity types, duration, and spatial distribution, linking activity hotspots to ecological features. This approach strengthened contextual support for associations between environmental conditions and behaviour, but did not establish causality.

4 Results

4.1 Measurement Model Assessment

The measurement model was first evaluated for reliability and validity. As shown in Table 1, all standardized factor loadings exceeded the recommended threshold of 0.70, ranging from 0.712 to 0.816, indicating that the observed indicators adequately represent their respective latent constructs. Cronbach's α values ranged from 0.819 to 0.880, rho_A values ranged from 0.824 to 0.882, and composite

reliability (CR) values ranged from 0.874 to 0.907, all exceeding the 0.70 criterion (Hair et al., 2019). These results demonstrate strong internal consistency and measurement stability of the constructs. Table 1 shows the Model fitting results.

Table 1. Model fitting results.

Constructs	Items	Factor Loading	Cronbach's α	rho A	CR	AVE
Ecological Experience（ECO）	ECO1	0.730	0.834	0.838	0.878	0.546
	ECO2	0.758				
	ECO3	0.714				
	ECO4	0.728				
	ECO5	0.775				
	ECO6	0.729				
Spatial Awareness (SPA)	SPA1	0.789	0.880	0.882	0.907	0.581
	SPA2	0.804				
	SPA3	0.770				
	SPA4	0.712				
	SPA5	0.778				
	SPA6	0.759				
Perception of health effects (PHE)	PHE1	0.763	0.862	0.865	0.897	0.592
	PHE2	0.781				
	PHE3	0.719				
	PHE4	0.769				
	PHE5	0.717				
	PHE6	0.794				
	PHE7	0.789				
Spatial satisfaction (SPS)	SPS1	0.720	0.819	0.824	0.874	0.581
	SPS2	0.762				
	SPS3	0.743				
	SPS4	0.766				
	SPS5	0.816				

Regarding convergent and discriminant validity, the AVE values for all latent constructs—ECO (0.546), SPA (0.581), PHE (0.592), and SPS (0.581)—exceeded the recommended threshold of 0.50, indicating satisfactory convergent validity (Fornell & Larcker, 1981). In addition, the square roots of the AVE values for each construct were greater than their corresponding inter-construct correlations, demonstrating adequate discriminant validity (Fornell & Larcker, 1981). Overall, the measurement model meets the requirements for PLS-SEM analysis and is suitable for subsequent structural model testing.

4.2 Structural Model Analysis
4.2.1 Overall Model Fit
The overall structural model fit is presented in Figure 3 and Table 2. The standardized root mean square residual (SRMR) was 0.073 (Saturated model = 0.073; Estimated model = 0.073), which is below the recommended threshold of 0.08 (Henseler et al., 2014), indicating a good overall model fit. The values of d_ULS (1.596), d_G (0.676), and the normed fit index (NFI = 0.747) were all within acceptable ranges, suggesting satisfactory structural adequacy.

Table 2. Collinearity analysis and model fit.

Dimension Correlation	VIF	SRMR
ECO -> PHE	1.914	Saturated model = 0.073
ECO -> SPA	1.000	Estimated model = 0.073
ECO -> SPS	2.045	d_ULS=1.596
PHE -> SPS	2.454	d_G=0.676
SPA -> PHE	1.914	NFI=0.747
SPA -> SPS	2.774	

The model showed moderate to substantial explanatory power, with R^2 values of 0.477 for Spatial Perception (SPA), 0.593 for Perceived Health Effect (PHE), and 0.654 for Spatial Satisfaction (SPS), indicating particularly strong prediction of overall satisfaction (Chin, 1998; Hair et al., 2019). Collinearity assessment revealed VIF values between 1.000 and 2.774, all below the threshold of 5, indicating no significant multicollinearity and confirming the stability of structural relationships (Hair et al., 2019). Overall, the model demonstrates adequate fit and explanatory strength, supporting further analysis of path coefficients and mediating effects.
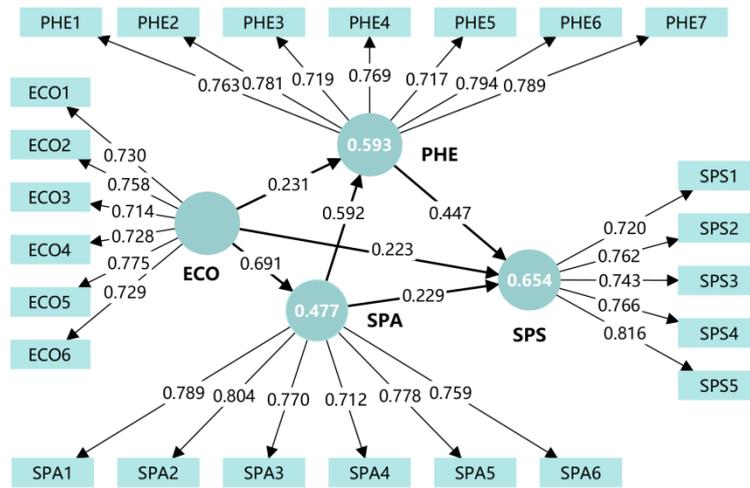
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Figure 4. Model of PLS-SEM path analysis diagram.

4.2.2 Path Coefficient Testing

Based on 5000-bootstrap resampling (Table 3), all hypothesized paths were statistically significant (p < 0.001), supporting H1–H6(Hair et al., 2019). Ecological Experience exerted a strong positive effect on Spatial Perception (β = 0.691, t = 19.322) and a moderate direct effect on Perceived Health Effect (β = 0.231, t = 17.289). Spatial Perception showed a stronger influence on Perceived Health Effect (β = 0.592, t = 10.430), highlighting its key mediating role between environmental conditions and health cognition. Perceived Health Effect significantly enhanced Spatial Satisfaction (β = 0.447, t = 4.716), while Ecological Experience (β = 0.223, t = 3.555) and Spatial Perception (β = 0.229, t = 2.673) also had direct positive effects on satisfaction. Overall, Perceived Health Effect serves as a central mechanism linking ecological experience to overall satisfaction.

Table 3. Assume the result of the path verification.

Hypothesis	Relationship	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	p Values	Decision
H1	ECO -> SPA	0.691	0.695	0.040	19.322***	0.000	Supported
H2	ECO -> PHE	0.231	0.231	0.072	17.289***	0.000	Supported
H3	SPA -> PHE	0.592	0.594	0.057	10.430***	0.000	Supported
H4	PHE -> SPS	0.447	0.449	0.095	4.716***	0.000	Supported
H5	ECO -> SPS	0.223	0.223	0.063	3.555***	0.000	Supported
H6	SPA -> SPS	0.229	0.229	0.086	2.673***	0.000	Supported

*** Statistical significance was achieved at p < 0.001.

4.3 Mediation Analysis

To examine the mediating mechanisms, indirect effects were tested using bootstrap analysis (Table 4). Results indicate that H7–H9 were all statistically significant (p < 0.001) (Hair et al., 2019; Preacher & Hayes, 2008). Ecological Experience indirectly influenced Perceived Health Effect through Spatial Perception (β = 0.409, t = 9.121), suggesting that ecological conditions first enhance health cognition by improving spatial perception. Ecological Experience also indirectly affected Spatial Satisfaction through Perceived Health Effect (β = 0.103, t = 2.485). Moreover, a significant chain mediation effect was identified, whereby Ecological Experience influenced Spatial Satisfaction through the sequential pathway of Spatial Perception → Perceived Health Effect (β = 0.183, t = 4.181), indicating the presence of multiple mediating mechanisms.

Table 4. Assume the result of the mediating path verification.

Hypothesis	Relationship	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	p Values	Decision
H7	ECO -> SPA->PHE	0.409	0.412	0.045	9.121***	0.000	Supported
H8	ECO -> PHE -> SPS	0.103	0.104	0.041	2.485***	0.000	Supported
H9	ECO -> SPA->PHE -> SPS	0.183	0.185	0.044	4.181***	0.000	Supported

*** Statistical significance was achieved at p < 0.001.

Overall, Ecological Experience influences Spatial Satisfaction both directly and indirectly through the sequential pathway of Spatial Perception and Perceived Health Effect, forming a partial mediation structure. These findings further support the environmental–behaviour theoretical framework, confirming the mechanism through which physical environments shape behavioural and attitudinal outcomes via perceptual evaluation processes.

4.4 Behavioural Validation

Behavioural mapping was used to validate the structural model findings. Results show that shaded semi-open areas with dense tree canopy had longer stays and higher levels of social and sedentary activities. Continuous green corridors and waterfront spaces formed clear activity clusters, supporting the positive link between ecological experience and spatial perception. Areas with greater environmental comfort also demonstrated stronger behavioural persistence and interaction. Overall, the spatial patterns reinforce the model, confirming that ecological improvements enhance older adults' public space use by strengthening spatial perception and health-related experiences.

5 Discussion

The findings indicate that ecological experience significantly enhances spatial perception, supporting the "environmental stimulus–perceptual evaluation" framework of environmental-behaviour theory (Gifford, 2014; Mehrabian & Russell, 1974). Features such as continuity of greenery, tree canopy shading, and microclimatic regulation improve environmental conditions, which in turn strengthen older adults' sense of safety and comfort. This creates an ecological–perceptual coupling mechanism (Kaplan & Kaplan, 1989; Sugiyama et al., 2008). Furthermore, spatial perception has a more pronounced effect on perceived health outcomes than the direct impact of ecological experience. This emphasizes its mediating role, as highlighted in restorative environment theory (Hartig et al., 2014; Kaplan & Kaplan, 1989), where ecological conditions translate into health benefits through psychological perception.

At the satisfaction level, the perceived health effect is a key determinant of overall evaluations. This indicates that older adults assess public spaces based on physical comfort and psychological well-being as well as functionality and visual appeal (Bowler et al., 2010; Hartig et al., 2014). Therefore, optimizing rural public spaces should shift from a facility-oriented approach to a health-oriented strategy. This shift would enhance spatial perception and health cognition through ecological improvements, aligning with the age-friendly framework (Organization, 2007). Behavioural observations support these structural pathways, demonstrating activity clustering in shaded semi-open areas, which reinforces the contextual validity of the model.
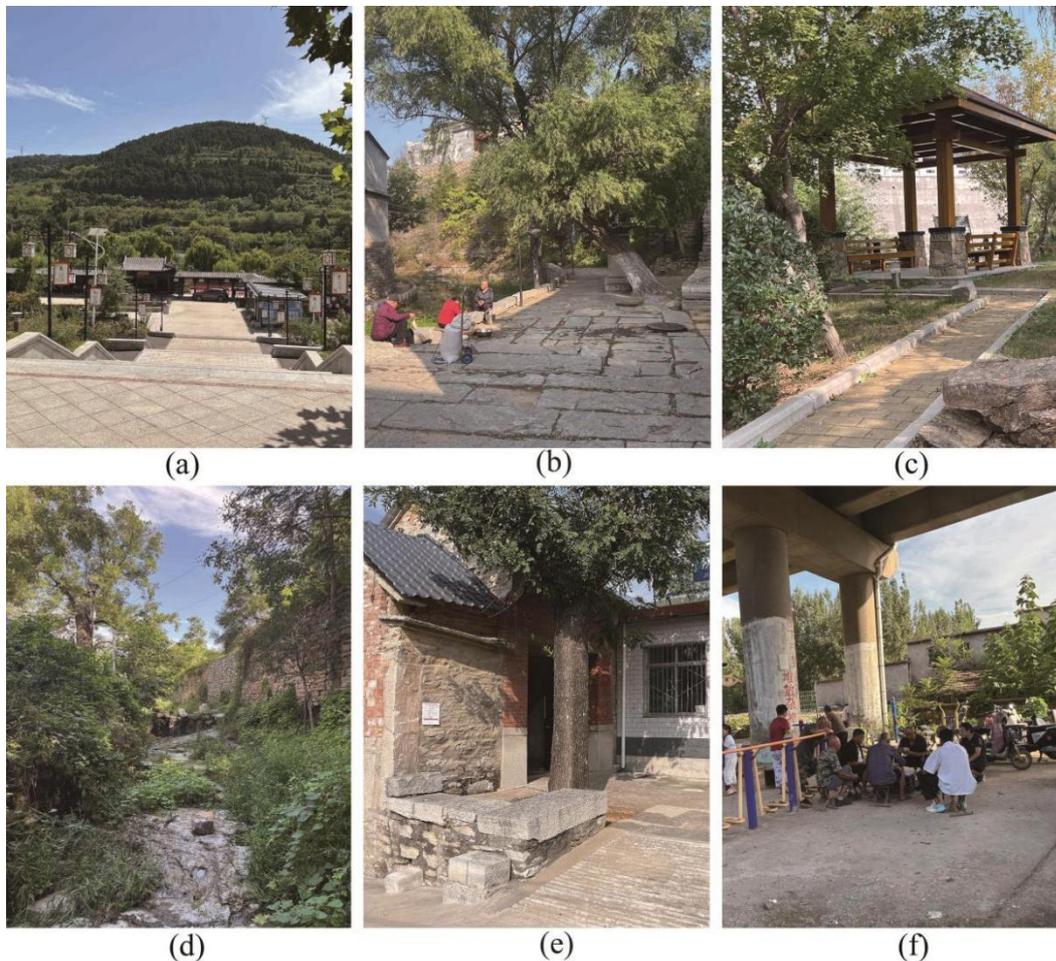

Figure 5. Representative ecological spatial conditions in Dongquan Village:(a) tree canopy shading in central square;(b) semi-open communication node;(c) Shade area under the tree; (d) waterfront microclimatic space;(e) residential transitional space;(f) activity clustering under shaded environment.

Rural public spaces are more closely linked to daily life and community networks compared to urban environments. In these settings, ecological elements are intricately connected to both production and living activities (Wang et al., 2015; Woods, 2010). This strong integration leads to a more direct and lasting impact of ecological experiences on spatial perception and health awareness, which aligns with existing research on rural landscapes (Wilson, 2008). The study validates a multi-path model demonstrating that ecological experiences influence satisfaction through spatial perception and perceived health effects. This highlights the combined role of ecological improvement and perceptual mechanisms, expanding environmental-behaviour theory to rural contexts and advancing research on age-friendly rural public spaces.

6. Conclusion

This study developed and tested a structural path model, "Ecological Experience–Spatial Perception–Perceived Health Effect–Overall Satisfaction," grounded in environmental–behaviour theory, to examine how ecological quality shapes age-friendliness in rural public spaces. Findings show that ecological experience—particularly greenery continuity and shading—enhances spatial perception, improving older adults' sense of safety and comfort. Spatial perception mediates the effects of ecological experience on perceived health benefits and overall satisfaction, with perceived health effect identified as the strongest determinant of satisfaction. Ecological experience also influences satisfaction directly and indirectly through sequential mediation. Observational data confirm that activities cluster in shaded, semi-open areas. The study extends environmental–behaviour theory to rural settings and highlights practical implications, suggesting that rural public space design should prioritize greenery and shading to support health-oriented, age-friendly environments. Future research should include multi-site comparisons, objective environmental measures, and account for seasonal or age-based variations.

Acknowledgement

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