

ASSESSMENT OF ELDERLY-ORIENTED SPATIAL VISUAL QUALITY IN POCKET PARKS: A NEW METHOD BASED ON PANORAMIC SEMANTIC SEGMENTATION

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ABSTRACT

As global population aging intensifies, pocket parks in high-density urban areas have emerged as vital venues for older adults' daily activities. However, existing research predominantly relies on roadway-captured street view imagery (SVI), which inadequately captures the internal spatial heterogeneity and micro-scale visual features of these parks. To address this, we evaluated the age-friendly spatial visual quality (SVQ) of 29 pocket parks on Xiamen Island from an internal panoramic perspective. We developed the Older-Adult Friendly Visual Quality Index (OAVQ-I) utilizing panoramic imagery and deep learning-based semantic segmentation to quantify six indicators: Green View Ratio (GVR), Natural Elements Richness (NER), Sky Openness (SO), Enclosure (Encl), Rest Facilities Visibility (RFV), and Walkable Space Ratio (WSR). Coefficient of variation (CV) objective weighting revealed that RFV, Encl, and SO exhibit the highest relative dispersion among the indicators, collectively comprising 87% of the total weight. Notably, a high GVR does not guarantee high quality; excessively dense vegetation can create an "ecological trap" by obstructing facilities and limiting light penetration. Comparative case analysis identified three distinct spatial patterns: high-quality friendly, moderately friendly, and low-quality (requiring improvement). This study advances urban green space evaluation from macroscopic statistical assessment to microscopic functional diagnosis. The findings suggest that urban renewal should transition from blindly increasing greenery to optimizing spatial quality – specifically by pruning mid-level vegetation to enhance facility visibility and illumination – thereby creating safer, more supportive environments for older adults.

Keywords: deep learning, elderly-friendly design, panoramic image, pocket park, spatial visual quality.

INTRODUCTION

BACKGROUND AND MOTIVATION

Rapid urbanization has driven the sustained concentration of urban populations and the continual expansion of city scales (Parekh & Gohil, 2022). These developments not only challenge urban infrastructure and resource allocation but also exert profound impacts on ecological environments and social structures (Kassouri, 2021; Veal, 2021). Although urbanization has improved infrastructure, it has concurrently fragmented public spaces in high-density areas. Simultaneously, global population aging has become increasingly pronounced (Nations, 2020). China serves as a pertinent example. Empirical studies indicate that by the end of 2019, the population aged 60 years and older had reached 254 million, representing 18.1% of the total population (Xu *et al.*, 2022).

As the proportion of the older population continues

to rise, their living requirements and health concerns have garnered increasing scholarly attention. Notably, daily activity needs are of particular significance. Urban green spaces furnish older adults not merely with fresh air and agreeable environments (Dimitrov-Discher *et al.*, 2022), but also with venues for walking, exercise, and social interaction (Ali *et al.*, 2022), thereby exerting positive effects on their physical and psychological well-being (Zhou *et al.*, 2022). However, large parks and green spaces often fail to meet the daily activity needs of older adults due to their remote locations. Pocket parks, characterized as small and dispersed urban green spaces, serve as an effective supplement to address these needs (Kerishnan & Maruthaveeran, 2021; Motomura *et al.*, 2024).

Spatial visual quality (SVQ), a key criterion for evaluating urban environmental comfort and livability, has long been a central research focus in urban planning, landscape design, and environmental psychology (Inglis *et al.*, 2022). Visual quality

constitutes a critical dimension of older adults' experiences in pocket parks. High-quality visual environments not only offer aesthetically pleasing and comfortable settings but also enhance spatial cognition and psychological well-being (Wang *et al.*, 2023). However, contemporary urban renewal frequently falls into the greening-only trap, overlooking the efficacy of visual elements in guiding older adults' behavior (Wu *et al.*, 2025a). Therefore, assessing the spatial visual quality of pocket parks for older adults holds significant practical implications for developing age-friendly environments.

LITERATURE REVIEW AND RESEARCH GAPS

Early research on spatial visual quality primarily relied on subjective perception evaluation, seeking to establish quantitative relationships between objective physical environments and human subjective perceptions through questionnaire surveys and psychophysical methods (Marans, 2003). The Semantic Differential (SD) method is a classic tool in environmental perception research. For instance, Santosa *et al.* employed this approach to evaluate the visual quality and public preferences of urban commercial street scenes (Santosa *et al.*, 2018). In their study of user satisfaction at the Historical City Square, Erdogan *et al.* employed questionnaire surveys to evaluate the physical, behavioral, and visual qualities of the landscape (Erdogan, 2016). Such studies are typically limited in scale or confined to specific contexts; for example, Mousavi Asl *et al.* examined the visual quality and light distribution in indoor spaces of medical centers (Mousavi Asl & Safari, 2021), Yunitsyna *et al.* investigated visual comfort in art classrooms (Yunitsyna & Toska, 2023), Sari *et al.* conducted evaluations of retail store space quality (Sari & Bekar, 2023).

Regarding the established evaluation indicators, this study examines three primary dimensions:

Structural indicators: These focus on the composition of spatial forms. For instance, Ma *et al.* examined the relationship between the visual quality of urban green space landscapes and human perceptions – including aesthetics, safety, and vitality – and identified 28 characteristic indicators, such as cleanliness and health status (Ma *et al.*, 2021). Mesa Carranza *et al.* proposed an indicator system encompassing ecological, aesthetic, and cultural dimensions for assessing urban landscapes in informal settlements (Mesa Carranza *et al.*, 2016).

Aesthetic/Perceptual Indicators: These focus on psychological experiences. Li *et al.* proposed the

“Interface-Element-Psychology” model, which categorizes the visual landscape of sidewalks into four dimensions: canopy, ground, roadside, and building facade. Drawing on elements such as “fascination” and “coherence,” they assessed the psychological restorative potential of these landscapes (Li *et al.*, 2024). Other studies have also examined core indicators of traditional SVQ research, including naturalness (Al-Akhzami, 2023), complexity (Zheng *et al.*, 2021), and legibility (Qi *et al.*, 2017).

Functional indicators: These focus on environmental support functions. While studies such as Tsang *et al.*'s primarily address indoor environmental quality (IEQ), their assessment of visual comfort also demonstrates how functional attributes influence perceptual experiences (Tsang *et al.*, 2023). Extensive research has established the theoretical foundations for visually evaluating urban streets, public squares, parks, and similar spaces. Nevertheless, these studies are frequently constrained by the temporal limitations and spatial coverage of manually collected data (Kang & Liu, 2022; H. Ma *et al.*, 2025; Nie *et al.*, 2019; Zhao & Lin, 2024).

Over the past decade, research methodologies have undergone a significant paradigm shift from traditional field surveys to approaches driven by big data and artificial intelligence. The widespread availability of Street View Image (SVI) data, coupled with advances in deep learning (DL) technology, has catalyzed a paradigmatic transformation in visual quality assessment. With their extensive spatial coverage, temporal continuity, and cost-effectiveness, street view images – such as Google Street View, Baidu Street View, and Tencent Street View – have emerged as a viable alternative to conventional field surveys. Tang *et al.* utilized Tencent Street View images to achieve, for the first time, quantitative measurement of visual quality and temporal changes in Beijing's hutong areas (Tang & Long, 2019). Wang *et al.* further employed time-series street view imagery to evaluate and monitor the equity and temporal dynamics of urban visual perception quality, thereby demonstrating its significant potential for longitudinal assessment (Z. Wang *et al.*, 2024). Although Street View Imagery (SVI) provides a continuous two-dimensional perspective, its data collection is largely constrained to roadside viewpoints. These viewpoints are monotonous and predominantly horizontal. Furthermore, vehicle-inaccessible areas hinder the comprehensive capture of three-dimensional, immersive visual experiences in small-scale spaces such as pocket parks (Olszewska-Guizzo *et al.*, 2023; Yosifof & Fisher-Gewirtzman, 2024). Advances in deep learning, particularly semantic segmentation,

have enabled accurate and automated extraction of visual elements – including vegetation, buildings, sky, roads, and sidewalks – from images (Liu *et al.*, 2025; Meng *et al.*, 2023). These advancements have enabled large-scale, objective, and quantitative assessment of spatial visual quality (Qin *et al.*, 2024; Tabatabaie *et al.*, 2023; Xu *et al.*, 2024). However, most machine learning models are trained on datasets derived from general population perceptual data, rendering the resulting indicator weights and predictive models of questionable applicability to older adults (Akbarishahabi, 2022; Liu & Zhao, 2025; Xuan & Zhao, 2022).

While previous studies utilizing street view imagery (SVI) have achieved extensive spatial coverage, they remain essentially roadway-centric in perspective. For pocket parks – deeply embedded within communities and characterized by diminutive scales – street view images fail to capture the heterogeneous characteristics inherent to these spaces. Furthermore, these studies exhibit an overreliance on GVR as the sole quality metric. However, for older adults with visual impairment and limited mobility, increased greenery does not necessarily equate to improved conditions. Presently, the literature lacks quantitative evaluation frameworks for facility visibility and perceived micro-scale enclosure. Consequently, pocket park renewal often proceeds without evidence-based support, and design guidelines typically remain generic, failing to address the visual conflicts among elements within parks of varying quality (e.g., greenery obstructing facilities).

To address these limitations, this study empirically examined 29 pocket parks on Xiamen Island as case studies, applying panoramic image technology to park interiors for the first time. Through the OAVQ-I index, key physical variables theoretically associated with age-friendly environmental perception were quantitatively identified, enabling a shift from macroscopic visual statistics to microscopic functional diagnosis.

OBJECTIVES AND CONTRIBUTIONS

Data Collection and Evaluation Methodology

This study employs panoramic imagery technology to capture comprehensive spatial information from an on-site experiential perspective within pocket parks. This approach addresses the lack of micro-scale spatial information inherent in traditional data sources, thereby more accurately reflecting older adults' visual perception during walking and resting

activities. By adopting this data collection method, the study evaluates the park's spatial environment from a perspective aligned with actual usage scenarios, enhancing both the authenticity and interpretability of the findings.

Refinement of the Evaluation Framework for Age-Friendly Design

This study employed machine learning techniques and coefficient of variation (CV) analysis to identify rest facility visibility (RFV), enclosure structure (Encl), and sky openness (SO) as the most spatially variable components of visual environmental quality for older adults. These three indicators collectively account for 87% of the total assigned weight in the evaluation model. The study further examines the interaction effects among these variables, revealing both synergistic and antagonistic relationships. The results indicate that increased greenery does not necessarily enhance spatial quality; excessively dense vegetation may compromise facility visibility and lighting conditions, thereby adversely affecting the visual environment. These findings provide a function-oriented indicator system for evaluating age-friendly design in pocket parks, extending beyond traditional green coverage rate metrics.

Spatial Diagnostic Method for Targeted Optimization

Building upon the evaluation model, this study conducts a comparative analysis of high-, medium-, and low-quality cases to develop a diagnostic framework oriented toward spatial optimization. The proposed heatmap analysis method enables the identification of potential visually deficient areas and safety risk zones within pocket parks, providing a quantitative basis for refined urban governance. Additionally, the study proposes spatial optimization strategies, including reducing excessive greenery, enhancing facility visibility, and improving lighting conditions. These strategies address practical demands for spatial quality improvement in pocket parks during high-density urban renewal, offering a feasible pathway for low-cost, high-efficiency micro-upgrades under constrained financial conditions.

MATERIALS AND METHODS

RESEARCH FRAMEWORK

Fig. 1 presents the research framework for evaluating the spatial visual quality of elderly-friendly pocket parks. The framework comprises three sequential

steps: (1) sampling point selection along internal park pathways, followed by visual data simulation from the older adult's perspective, image parameter calibration, and geographic coordinate matching; (2) image grouping and semantic segmentation of street view data using a Mask2Former-based network model initialized with ADE20K pre-trained weights, with subsequent accuracy verification and visual parameter extraction; and (3) aggregation of parameters by sampling points and sections onto geographic elements to construct a geographic information database of pocket park spatial visual quality and characteristics, enabling further analysis and discussion.

EVALUATION INDEX SYSTEM CONSTRUCTION

This study employs a subjective evaluation approach to measure the built environment. Rooted in Post-Occupancy Evaluation (POE) theory, this method has emerged as a core approach for environmental assessment and has proven effective in evaluating the quality of existing environments (Morley, 2025; Roberts *et al.*, 2019). This study focuses on pocket parks and their elderly-friendly attributes. Accordingly, the evaluation framework must transcend conventional street space assessment criteria and prioritize the restorative qualities, safety, and usability of the park environment. By integrating older adults' perceptual preferences and behavioral patterns, this research constructs a multi-dimensional index system encompassing Landscape Amenity, Spatial Comfort and Scale and Elderly-Friendly Functional Support. Furthermore, it underscores the facilitative role of environmental cues in older adults' spatial cognition, thereby enhancing the explanatory power and micro-scale applicability of the evaluation model (Wu *et al.*, 2025b) (Young *et al.*, 2020).

Landscape Amenity quantifies the naturalness and therapeutic potential of parks, comprising Green View Rate (GVR) and Natural Elements Richness (NER):

GVR is currently among the most mature and widely used indicators for quantitatively assessing urban green exposure from street view images (Fengjing *et al.*, 2022). Elevated GVI exhibits a strong positive correlation with both physical and mental health outcomes among older adults (R. Wang *et al.*, 2024). In elderly-friendly parks, a high Gaze Viewing Range (GVR) provides visual comfort that effectively alleviates urban stressors and promotes cardiovascular relaxation, thereby directly supporting the park's therapeutic function (Zhifeng & Yin, 2021). Visual greenery is a key factor in attracting older adults to parks. Research indicates

that older adults tend to prefer paths and landscapes with higher greenery visibility (Wang & Rodiek, 2019). Street-level greenery, as quantified by GVR, significantly promotes walking behavior. Higher levels of streetscape greenery are associated with extended walking duration among older adults (Yang *et al.*, 2021). In pocket parks, a higher GVR indicates superior environmental aesthetics and enhanced natural immersion, increasing older adults' willingness to engage in outdoor activities and prolonging their stay, thereby indirectly promoting physical activity levels – particularly crucial for improving their overall quality of life (Wang *et al.*, 2023).

Abundant natural elements enhance environmental aesthetic value and demonstrate a significant positive correlation with older adults' subjective well-being and positive affect (Guan *et al.*, 2025). Within Landscape Therapy theory, water bodies – rivers and lakes in particular – serve as distinctive elements that significantly promote serenity and relaxation. The NER index incorporates non-vegetative natural elements, including water bodies and floral features, to capture the spatial heterogeneity and compositional diversity of park landscapes (Wang, 2025). Such diversity is hypothesized to yield multi-sensory stimulation and experiential richness, consequently augmenting landscape complexity and perceived attractiveness (G. Ma *et al.*, 2025). Pocket parks function as "miniature ecological islands" within urban environments, with their performance largely depending on the compact and diverse configuration of landscape elements, particularly the proportion and spatial arrangement of natural components (Yin *et al.*, 2023). The NER indicator encourages maximizing natural element diversity and combination within limited spaces, closely aligning with pocket park design objectives.

Spatial Comfort and Scale assesses physical comfort and thermal adaptability in spatial configurations – a dimension critical for older adults, comprising Sky Openness (SO) and Enclosure (Encl):

Expansive sky views constitute a critical element of natural environments conducive to psychological restoration. Environmental psychology research demonstrates that heightened sky visibility symbolizes openness, freedom, and lack of constraint, thereby activating psychological relaxation mechanisms and alleviating anxiety and stress (Masoudinejad & Hartig, 2020). Such unobstructed visual access to nature represents a scarce therapeutic asset in urban settings (Wu *et al.*, 2020). Pocket parks are typically small in scale. Overshadowed by tall buildings or dense tree canopies, they may induce oppression and claustrophobia. For older adults with declining perceptual abilities, such

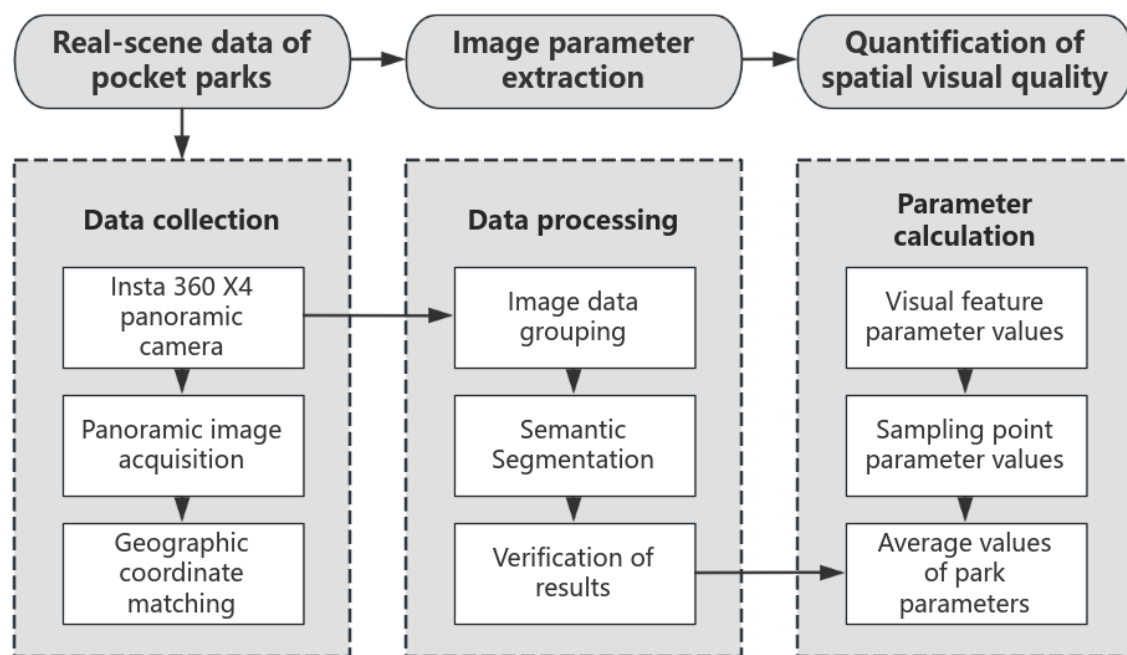


Fig. 1. Research framework of pocket park spatial visual quality evaluation.

environments heighten cognitive load and discomfort (Wang *et al.*, 2019). High openness effectively alleviates perceived oppression by creating a visually expansive space, thereby mitigating psychological pressure in confined environments (Kajosaari & Pasanen, 2021).

The degree of spatial enclosure critically affects how older adults engage with park environments (Levinger *et al.*, 2025). The semi-enclosed spaces created through vertical elements such as fences, shrubs, or landscape ornaments establish territorial boundaries that enhance user privacy (Ruchi). This clear boundary mitigates external disturbances, enhancing older adults' perceived security and comfort during rest or social activities – an essential psychological feature of age-friendly design (Kimić & Polko, 2022). Enclosing elements (e.g., fences and walls) define and demarcate spatial functions, thereby enhancing park legibility. Clear boundaries enable older adults to readily identify entrances, exits, and functional zones, which improves overall spatial comprehension (Askarizad & He, 2022). Such structural clarity mitigates environmental uncertainty among older adults, which in turn lessens the psychological burden attributable to complex surroundings (Yafei *et al.*, 2023).

The Elderly-Friendly Functional Support (EFS) index quantifies how well a space accommodates older adults' behavioral and physiological needs, comprising

two indicators: Rest Facilities Visibility (RFV) and Walkable Space Ratio (WSR):

Declines in physical endurance with age necessitate more frequent rest periods. Access to seating infrastructure – specifically benches and chairs – serves as a critical determinant of how often, how long, and how satisfactorily older adults engage in outdoor activities (Hubl, 2019). Visibility of resting areas in complex or unfamiliar settings enhances perceived control and psychological security among older adults (Levinger *et al.*, 2025). Facility provision significantly influences older adults' subjective well-being. The availability and visibility of amenities signal that park managers are responsive to older adults' needs, thereby enhancing their sense of comfort and safety. Resting facilities, such as benches and tables, serve as primary venues for social interaction, observation, and gathering.

Walking constitutes the predominant and safest exercise modality for older adults. In urban green areas, path length and paved surface area demonstrate significant positive associations with older adults' step counts and caloric expenditure (Wang & Yao, 2025). For older adults with declining mobility and elevated fall risk, safe, level, and unobstructed walking surfaces constitute a core design requirement. The hardscape areas quantified by the WSR metric offer greater walking stability than grasslands (Plaut *et al.*, 2021). This indicator macroscopically ensures sufficient and

continuously accessible space throughout the park, satisfying older adults' requirements for environmental accessibility and safety. The walkable space functions as a connective framework linking all functional elements (e.g., rest areas and activity zones), enabling older adults to navigate seamlessly between areas, thereby ensuring overall park usability and establishing a fully functional, age-friendly recreational environment (Zhang *et al.*, 2023).

In summary, this study develops a six-indicator evaluation framework comprising Green View Rate (GVR), Natural Elements Richness (NER), Sky Openness (SO), Enclosure (Encl), Rest Facilities Visibility (RFV), and Walkable Space Ratio (WSR). The visual elements encompassed within each indicator and their corresponding calculation formulas are presented in Tab. 1. All indicators are computed based on the pixel proportion of semantic elements extracted from panoramic images.

Note: R_k is the value of evaluation indicator k (e.g., GVR or NER), expressed as a percentage. A_{total} is the total number of pixels in the segmented panoramic image; A_i is the number of pixels assigned to semantic category i ; and A_{sky} is the number of pixels assigned to the sky category. S_k denotes the set of semantic category indices included in indicator k , so $\sum_{i \in S_k} A_i$ is the total number of pixels assigned to those categories.

RESEARCH AREA

Xiamen represents one of the earliest cities in Fujian Province, as well as nationwide, to enter the stage of advanced aging (Fig. 2). According to a bulletin released by the Xiamen Municipal Civil Affairs Bureau and the Elderly Affairs Office, the city's aging problem has intensified, with both the number and proportion of older adults reaching decadal highs; this trend is particularly pronounced in the core urban area of Xiamen Island. Furthermore, relevant policy documents indicate that developing an "age-friendly city" constitutes a primary strategic objective in Xiamen's urban planning agenda.

Xiamen Island exemplifies a high-density built environment characterized by scarce land resources. The construction of pocket parks serves as the principal strategy to improve green space accessibility and enhance living environment quality for residents. Investigating the visual quality of micro-green spaces in high-density urban contexts addresses the critical challenge of maximizing green benefits within spatially constrained settings. The urban morphology of Xiamen Island thus provides an ideal experimental setting for examining elderly-friendly design in "small-scale, high-density" environments.

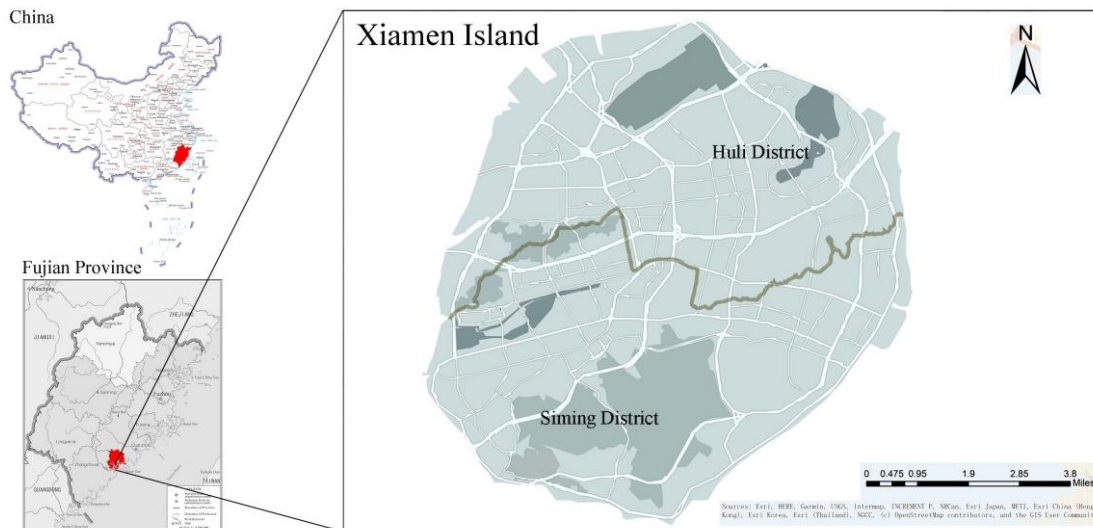
Accordingly, this study selected 29 completed pocket parks on Xiamen Island (encompassing Siming and Huli Districts) as the research sites. By quantifying visual quality indicators – including green coverage ratio, sky openness, and facility visibility – this research provides data-driven optimization strategies for both the renovation of existing spaces and the design of new additions in Xiamen. These findings support the city's transition from "livable" to "age-friendly livable" and offer significant reference value for other coastal cities in China undertaking adaptive retrofitting initiatives to address population aging.

DATA COLLECTION

This study focused on pocket parks ($\leq 1,000 \text{ m}^2$) with clearly defined internal road layouts. Given that older adults' visual field extends approximately 500 meters (Song *et al.*, 2024), panoramic image data were manually collected to simulate their movement patterns and characteristics within these parks; collection points were strategically positioned accordingly. Preliminary observations indicated that older adults typically gathered in the parks each afternoon and began dispersing around 6:00 p.m. Accordingly, data collection was scheduled between 3:00 p.m. and 6:00 p.m. daily to capture peak activity periods. From August 19 to September 1, 2024, panoramic images were collected at 29 pocket parks on Xiamen Island. Collection points were established at all park entrances and exits, as well as at each road intersection. For straight segments shorter than 5 meters, no points were assigned; for segments 5–10 meters, points were placed at the midpoint; for segments exceeding 10 meters, points were spaced at 20-meter intervals. For curved paths, points were positioned at each directional change along prominent turning lines. This systematic approach ensured comprehensive coverage of walking paths and all park scenarios (Fig. 3), yielding 496 collection points and corresponding panoramic images captured using an Insta360 X4 camera. This camera automatically records geolocation coordinates, timestamps, and ambient lighting conditions for each image, ensuring data consistency and traceability. All images underwent standardized preprocessing using Python's OpenCV library, including noise reduction and brightness equalization to mitigate weather-related interference (e.g., rain or intense sunlight), thereby facilitating subsequent semantic segmentation and visual element extraction. It should be explicitly noted that the raw panoramic image dataset and sampling locations utilized in this study originate from a comprehensive, multi-phase field campaign investigating urban pocket parks on Xiamen Island. While previous

Table 1. *Evaluation indicators for visual quality of elderly-friendly pocket parks.*

Indicator	Formula	Explanation
Green View Ratio, GVR	$R_{GVR} = \frac{\sum_{i \in S_{Vegetation}} A_i}{A_{total}} \times 100\%$	The total pixel area of the vegetation elements (including tree, grass, plant, flower, etc.).
Natural Elements Richness, NER	$R_{NER} = \frac{\sum_{i \in S_{Nature}} A_i}{A_{total}} \times 100\%$	The total pixel area of the natural element collection (including all vegetation elements, water elements such as sea, river, etc.).
Sky Openness, SO	$R_{SO} = \frac{A_{sky}}{A_{total}} \times 100\%$	The pixel area of the sky element.
Enclosure, Encl	$R_{Encl} = \frac{\sum_{i \in S_{Vertical\ Barrier}} A_i}{A_{total}} \times 100\%$	The total pixel area of all vertical obstruction elements (including buildings, walls, fences, poles, etc.).
Rest Facilities Visibility, RFV	$R_{RFV} = \frac{\sum_{i \in S_{Rest\ Facility}} A_i}{A_{total}} \times 100\%$	The total pixel area of the elements of rest facilities (including benches, chairs, tables, stools, etc.).
Walkable Space Ratio, WSR	$R_{WSR} = \frac{\sum_{i \in S_{Walkable\ Pavement}} A_i}{A_{total}} \times 100\%$	The total pixel area of all the elements of walkable paving (including path, sidewalk, floor, runway, etc.).

Fig. 2. *Study area.*

publications derived from this overarching project utilized the same raw imagery to explore the subjective psychological safety perception of the elderly using predictive machine learning models (e.g., LightGBM and SHAP) (Wu *et al.*, 2025a; Wu *et al.*, 2025b), the present study introduces a genuinely novel and distinct analytical framework. Specifically, this manuscript shifts the research paradigm from subjective safety prediction to an objective Spatial Visual Quality (SVQ) assessment. It extracts an entirely different set of functional affordance indicators (such as Rest Facilities Visibility, Sky Openness, and Enclosure) and employs Coefficient of Variation (CV) weighting to develop the OAVQ-I index, thereby providing structural diagnostic tools and specific micro-renewal

strategies (e.g., avoiding "ecological traps") that have not been previously published.

IMAGE SEGMENTATION AND VERIFICATION PROTOCOL

We employ Mask2Former – a Transformer-based image segmentation framework – to address the challenges of complex scenes and diverse object categories inherent in the ADE20K dataset (Cheng *et al.*, 2022). By reformulating pixel-level classification as mask classification, the proposed method leverages the Transformer's global attention mechanism and mask prediction capability to more effectively handle multi-class, multi-scale objects in the ADE20K dataset (Li *et al.*, 2023). The ADE20K dataset, developed

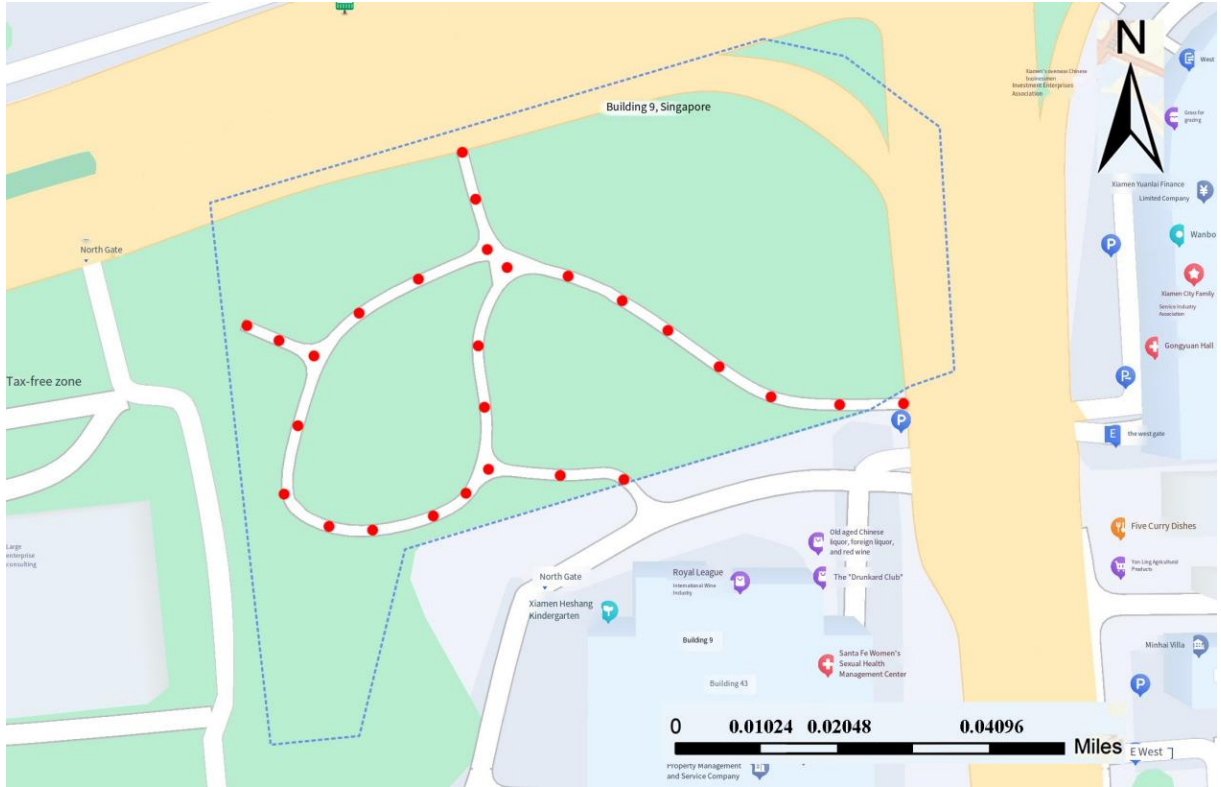


Fig. 3. Sample point layout diagram.

by the Computer Science and Artificial Intelligence Laboratory (CSAIL) at the Massachusetts Institute of Technology (MIT), is a large-scale, high-quality benchmark for scene parsing. It has been widely adopted for computer vision tasks, including semantic segmentation and scene understanding (Shafiq & Gu, 2022). To bridge domain gaps between general scenes and micro-park environments, the model was fine-tuned on an independent training dataset consisting of 500 custom-annotated panoramic images (collected from a separate pre-survey to prevent data leakage), initialized with ADE20K pre-trained weights. Training was performed using PyTorch on an [NVIDIA RTX 3090] GPU. The AdamW optimizer was employed with a weight decay of [0.05], an initial learning rate of [0.0001], and a polynomial decay schedule. The batch size was [8], and training comprised [80,000] iterations. This model achieved a global pixel accuracy (GPA) of 97.6% on the target micro-park dataset, thereby ensuring reliable quantitative analysis of visual indicators.

To ensure the accuracy and reliability of segmentation results, this study employed Adobe Photoshop 2022 for visual interpretation of key panoramic image components, including greenery, sky, roads, and buildings. Five panoramic samples from diverse pocket park scenes were randomly selected to compare semantic segmentation outputs against visual interpretation

results (Tab. 2). The proposed framework demonstrates robust performance in semantic segmentation of pocket park panoramic images, achieving an overall accuracy of 97.6% based on mean sample error calculations, which meets the research requirements. Image segmentation results were quantitatively analyzed using metrics specified in Table 1. Green coverage ratio and natural element diversity were calculated to evaluate spatial visual quality, providing empirical support for subsequent analyses. While overall global pixel accuracy (GPA) demonstrates macro-level reliability, detecting small-scale elements like rest facilities remains a challenge. We addressed this by employing the Mask2Former architecture, whose global attention mechanism effectively prevents small object masks from being overwhelmed by background classes. Qualitative visual validation (as seen in the semantic segmentation outputs for Park 11 and Park 25 in Table 2) confirms that the model successfully and consistently captures minute rest facilities, providing confidence in the extraction of the RFV indicator.

Table 2. Visual segmentation accuracy validation.

Park ID	Panoramic image	Semantic segmentation image	Program discrimination % / Visual discrimination % (difference in results, %)			
			Pedestrian area	Building	Sky	Vegetation
11			26.71/29.94 (3.23)	4.14/5.99 (1.85)	2.62/5.33 (2.71)	53.40/51.12 (-2.28)
12			28.10/28.80 (0.70)	2.50/4.15 (1.65)	2.93/8.72 (5.79)	58.23/56.16 (-2.07)
21			0.24/3.61 (3.37)	2.26/2.85 (0.59)	7.10/13.76 (6.66)	54.40/50.91 (-3.49)
2			11.19/16.05 (4.86)	3.45/3.72 (0.27)	3.98/0.64 (-3.34)	76.12/74.60 (-1.52)
25			1.35/1.61 (0.26)	1.64/3.12 (1.48)	2.33/3.12 (0.79)	62.90/61.68 (-1.22)

CONSTRUCTION OF THE COMPREHENSIVE VISUAL QUALITY INDEX OF ELDERLY-FRIENDLY POCKET PARKS

Given 29 pocket parks distributed across Xiamen Island, the Elderly-Friendly Visual Quality Index (OAVQ-I) was developed using the coefficient of variation (CV) – an objective weighting technique that allocates greater weights to more dispersed variables (Zhao *et al.*, 2022). Prior to calculating the CV and OAVQ-I, standardization is required to eliminate unit discrepancies and numerical range variations among the six indicators (e.g., GVR and NER). The standardization formula is as follows, where Z_i denotes the standardized value and X_i represents the original value for each indicator:

$$Z_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \quad (1)$$

Subsequently, calculate the coefficient of variation CV_i and weight W_i for each indicator. The CV method determines indicator weights by their relative dispersion. As variability increases, so does the discriminatory power across samples, warranting proportionally greater weight assignments.

$$CV_i = \frac{\sigma_i}{\mu_i} \quad (2)$$

$$W_i = \frac{CV_i}{\sum_{j=1}^6 CV_j} \quad (3)$$

In the formula, σ_i denotes the standard deviation of the standardized value Z_i for indicator i across 496 sampling points, while μ_i represents the arithmetic mean of Z_i for the same indicator and sampling points. The index j ranges from 1 to 6 across all indicators, with the constraint that the sum of weights W_i equals 1. The weights assigned to the six indicators are presented in Fig. 4.

The comprehensive visual quality index for older adults is calculated as follows:

$$\text{OAVQ-I} = \sum_{i=1}^6 \left(\frac{CV_i}{\sum_{j=1}^6 CV_j} \right) Z_i \quad (4)$$

This study employed Min-Max Normalization to standardize the six extracted visual indicators. Critical to this process was the definition of indicator polarity. Drawing on environmental psychology and age-friendly design principles, SO, WSR, RFV, and NER were designated as positive indicators within the typical range of pocket park data.

However, GVR and Encl do not exhibit strictly monotonic relationships with age-friendly space quality. Older adults prefer moderate enclosure to maintain security rather than complete isolation. Similarly, while moderate GVR offers psychological restoration, excessive vegetation density may produce adverse effects. Given that most pocket parks in the current dataset exhibited moderate to low values for

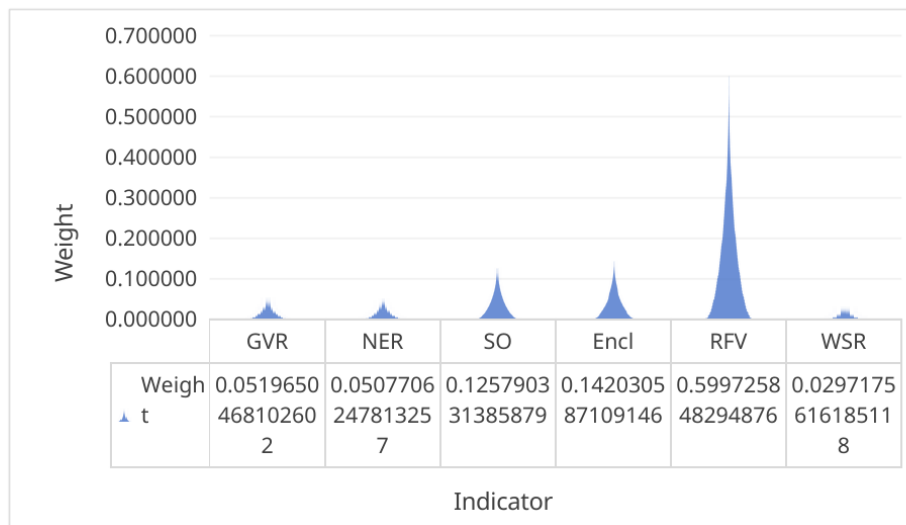


Fig. 4. Indicator weight.

Encl and GVR – below the negative threshold – they were linearly standardized as positive indicators at this stage to establish a benchmark model. The threshold effects of their extreme values will be specifically addressed in the subsequent discussion.

RESULTS

SPATIAL DISTRIBUTION OF SPATIAL VISUAL QUALITY IN ELDERLY-FRIENDLY POCKET PARKS

Fig. 5(a–f) presents the distribution of six indicators across all samples. Regarding the natural environment – a primary concern for older adults – the GVR and NER demonstrate strong consistency and dominance. The median (Q2) values for GVR and NER are 0.453 and 0.460, respectively, indicating that vegetation and natural elements typically occupy nearly half of the visual field in most pocket parks. This configuration provides older adults with positive ecological perception and visual restoration benefits. Both indicators exhibit an interquartile range (IQR) of approximately 0.27, with box plots revealing substantial variability (Fig. 5a, b). For instance, GVR medians exceed 0.6 in certain parks (e.g., Park 2 and Park 22), characterized by lush greenery, whereas Park 4 shows a GVR median below 0.1, indicating severely limited green visibility. This marked spatial heterogeneity suggests that the greening quality of some pocket parks falls considerably short of age-friendly design standards.

The median SO value is 0.132 (IQR = 0.186). Box plots reveal substantial variation across parks (Fig. 5, c). Certain parks (e.g., Parks 8 and 9) offer open sky views conducive to natural lighting, whereas others are obstructed by surrounding buildings or dense vegetation, resulting in reduced sky visibility. This limitation may cause insufficient lighting, potentially affecting vitamin D synthesis and reducing older adults' willingness to engage in outdoor activities during winter months.

The median WSR is 0.280 (IQR = 0.142). As shown in Fig. 5, f, samples are relatively uniformly distributed, indicating that most pocket parks provide adequate hard-paved areas that generally accommodate walking, circulation, and wheelchair use among older adults.

RFV values are notably low, with a median approaching zero (0.0002); even the third quartile (Q3) reaches merely 0.002. Box plots (Fig. 5, e) demonstrate that most parks have boxes compressed at the lower extreme, with only sporadic high values (e.g., Park 11). This suggests that recreational facilities such as seating and exercise equipment remain largely invisible to older adults across most visual scenarios. Such limited visibility not only diminishes functional appeal but also impedes usage by frail individuals who require clearly identifiable resting facilities.

The median Encl value is 0.061 (IQR = 0.063), indicating generally low enclosure. As illustrated in Fig. 5, d, most data cluster below 0.1. Although low enclosure facilitates sight lines and supports crime prevention through environmental design (CPTED), it may simultaneously indicate insufficient shelter and

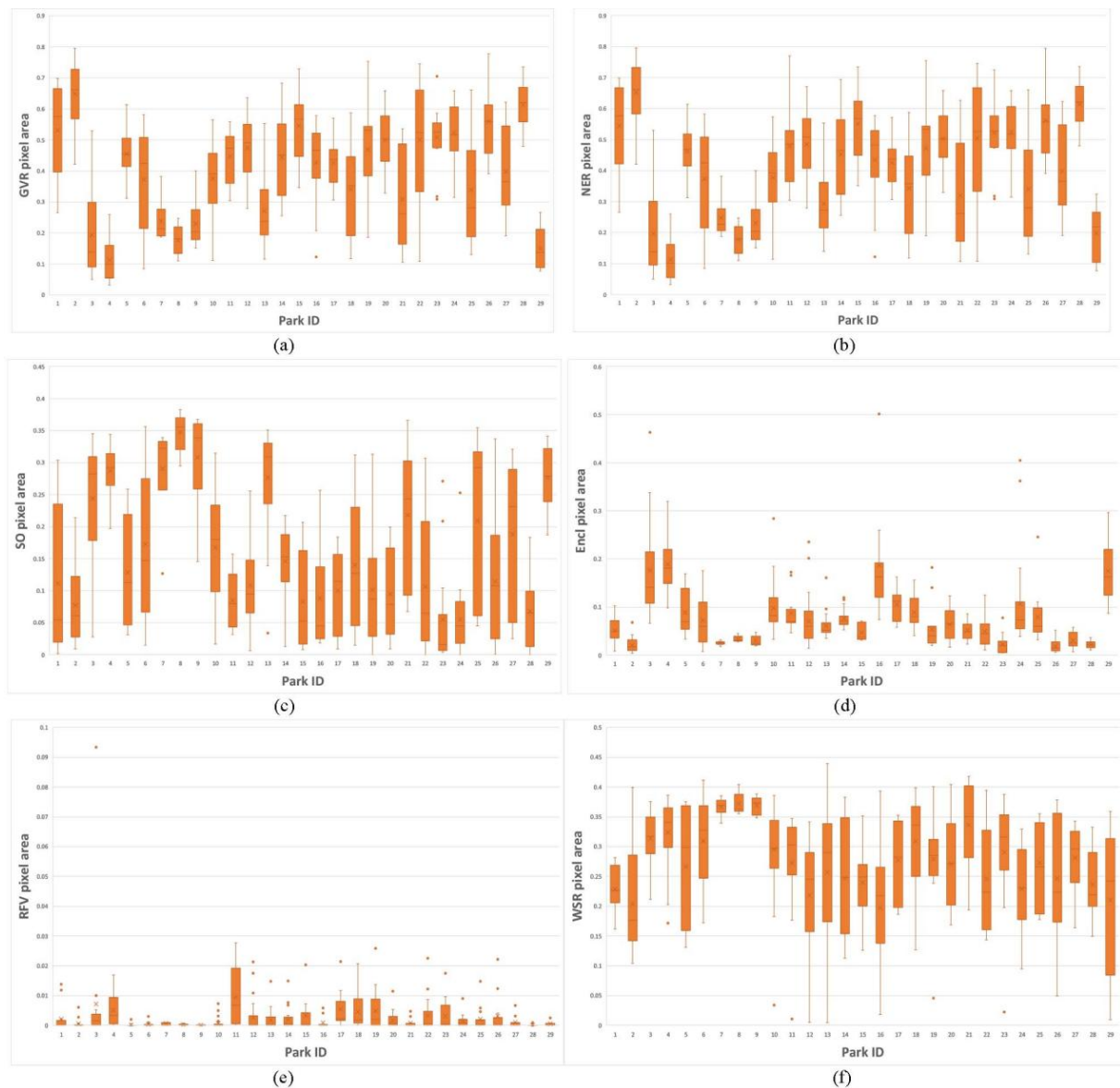


Fig. 5. Box plot of the single indicator of visual quality of elderly-friendly pocket parks: (a) GVR; (b) NER; (c) SO; (d) Encl; (e) RFV; (f) WSR.

spatial definition, rendering spaces overly exposed and lacking private or semi-private niches suitable for older adults to linger and socialize.

COMPREHENSIVE SPATIAL VISUAL QUALITY ASSESSMENT AND SPATIAL VARIATION OF ELDERLY-FRIENDLY POCKET PARKS

Using formula (4), OAVQ-I values were computed for all 29 parks. To enable scientific classification and inform design practice, this study applied quartile-based grading. This approach mitigates the arbitrariness of manual thresholds and objectively reflects sample distributions (Tab. 3).

Note: In this study, Q_1 represents the 25th percentile of the OAVQ-I data from 29 parks, and Q_3 represents the 75th percentile. Through calculation, we obtain $Q_1 = 0.079637$ and $Q_3 = 0.083860$.

Fig. 6 illustrates the spatial distribution of OAVQ-I across 29 pocket parks on Xiamen Island. The estimated elderly-friendly spatial visual quality exhibits a distinct spatial pattern: high values concentrated in the southwest (red and orange zones), moderate values in the northeast (yellow and green zones), and degraded patches in the central area (continuous green zones). Urban renewal in Siming District's old city has yielded high-quality visual environments, whereas Luhui District and central Siming District exhibit significant quality deficiencies.

Table 3. Grading standard for the visual quality index of pocket parks.

Evaluation grade	Classification criteria	Significance of design guidance
High-quality friendly type	$OAVQ-I \geq Q_3$	An outstanding example in the sample. The experience of this type of park should be promoted and learned from.
Moderately friendly type	$Q_1 < OAVQ-I < Q_3$	The quality has met the standards, but there is still room for improvement. Specific optimizations need to be carried out on the weak indicators.
Improvement needed - low quality type	$OAVQ-I < Q_1$	There are systematic flaws in the quality. It should be regarded as a key intervention target for future urban renewal and transformation.

High-Quality Friendly Type parks, represented by red and orange zones, form a pronounced high-value cluster in southwestern Siming District – the historic core – indicating that all pocket parks in this area achieve high-quality standards and serve as benchmarks for the island. Park No. 16 (the peak value) and Park No. 29 in Hulin District (the sole representative in this area) demonstrate that high-quality parks are sporadically distributed in the central urban area and eastern new town, lacking spatial contiguity.

Moderately Friendly Type parks, indicated by light orange, yellow, and light green zones, are widely distributed in central Siming District and the hinterland of Hulan District. For instance, Parks No. 26 and No. 24 in Hulan District (near the high-quality threshold) possess acceptable baseline visual conditions but exhibit deficiencies in specific indicators, precluding top-tier classification. Some parks in yellow zones approach the low-quality threshold; without adequate maintenance, they risk deterioration into low-quality spaces.

Improvement-Needed (Low-Quality) parks appear as distinct dark and light green zones. Spatially, two low-value clusters are evident. The first comprises Parks No. 6–9 in central Siming District; despite its central location, this area exhibits continuous low-value green zones, suggesting potential issues such as insufficient lighting or outdated facilities. The second consists of scattered dark green patches in Huli District (e.g., No. 23 and No. 18), which represent priority areas requiring urgent intervention for elderly-friendly renovation.

TRACING THE PRIMARY SOURCES OF INTRA-PARK SPATIAL VARIATION

As shown in Fig. 4, the combined weights of RFV, Encl, and SO account for 87% of the total indicator weight in OAVQ-I. This indicates that spatial variations in these three indicators explain the majority of OAVQ-I differences within parks. The remaining indicators – GVR, NER, and WSR – collectively

contribute less than 13%. To identify the key factors driving these spatial differences, this study selected three representative parks for further analysis: Park 3 (highest OAVQ-I score, representing high quality), Park 5 (OAVQ-I score closest to Q_3 [0.083860], representing medium potential), and Park 23 (lowest OAVQ-I score, representing low quality). The specific performances of RFV, Encl, and SO were then compared across these cases.

Fig. 7 presents thermal maps illustrating the spatial distribution of RFV, Encl, and SO in Park 3, a high-quality representative case. The RFV map reveals a pronounced monocentric polarization pattern: facilities are not evenly distributed but concentrated in specific “core activity zones.” This configuration enhances visual search efficiency for older adults at key nodes – facilities maintain high visual salience where rest or exercise occurs, while walking areas retain clear visual perception. The Encl map indicates that high-containment areas are concentrated primarily along the park periphery (behind seating), with internal pathways and activity centers maintaining low containment. This “peripheral enclosure, internal openness” structure addresses older adults’ territoriality needs while adhering to CPTED principles, ensuring mutual visibility and eliminating blind spots that induce perceived insecurity. The SO map shows high values across nearly the entire park, indicating that older adults consistently experience environments with adequate lighting and expansive visibility during activities.

Fig. 8 presents the thermal maps of RFV, Encl, and SO spatial distributions in Park 5, a representative medium-potential site. The RFV map exhibits a uniformly cool chromatic pattern (blue/green) without significant high-value clustering centers (red), indicating a pervasive lack of visual guidance for facilities. This “global cold spot” pattern suggests that elderly visitors cannot readily detect seating or fitness equipment within their visual field. The Encl map is predominantly light-toned, reflecting low enclosure; however, an anomalous dark red dot with intense contrast appears at a specific location, disrupting

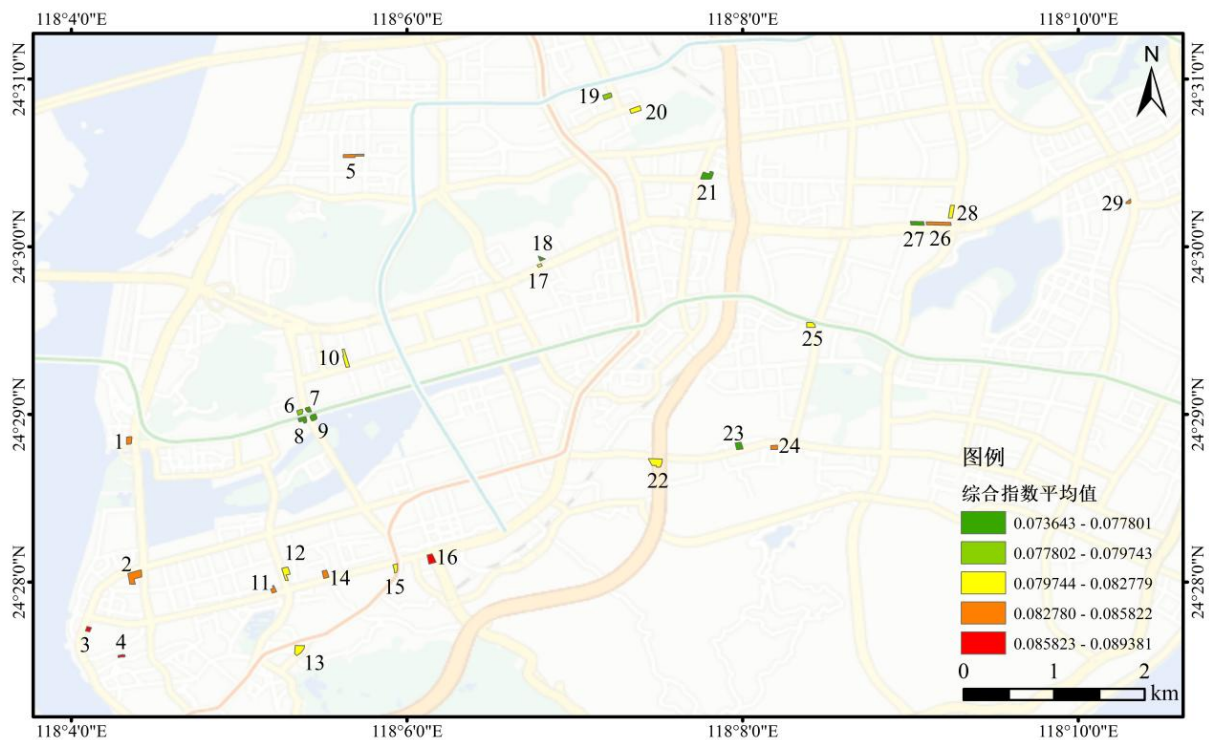


Fig. 6. Average OAVQ-I spatial distribution of the 29 pocket parks on Xiamen Island.

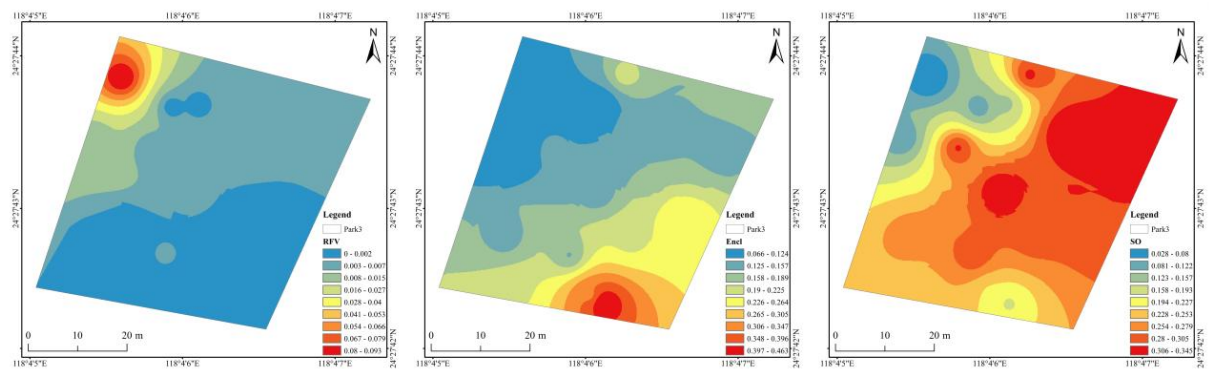


Fig. 7. High-quality representation of the internal RFV, Encl, and SO spatial distribution heat maps in Park 3.

spatial homogeneity. This singular protrusion marks an excessively dense "visual blind spot." The SO map displays a fragmented configuration characterized by alternating high-value (warm) and low-value (cool) zones, lacking continuous open corridors. Such fragmentation implies an uneven light environment, which may increase visual fatigue and fall risk for elderly pedestrians.

Fig. 9 presents heat maps illustrating the spatial distributions of RFV, Encl, and SO in Park 23, a representative low-quality site. The RFV heat map displays predominantly cool tones (deep blue/green), with sparse warm-colored patches and no red zones throughout. This indicates a lack of seating, fitness equipment, or resting facilities within the visual

field of older adults, suggesting that the park functions merely as a passive green buffer. The Encl heat map is characterized by generally low values, yet exhibits an isolated high-value patch with marked spatial discontinuity. This fragmented pattern reflects inadequate spatial definition: most areas are excessively open and lack territoriality, while abrupt high-value points likely result from disorganized structures or dense shrubbery. The SO heat map is dominated by dark low-value areas with minimal bright spots, indicating either dense upper canopy cover or severe obstruction from surrounding high-rise buildings. Such poor lighting conditions not only preclude sunbathing opportunities but also impede depth perception of ground-level variations,

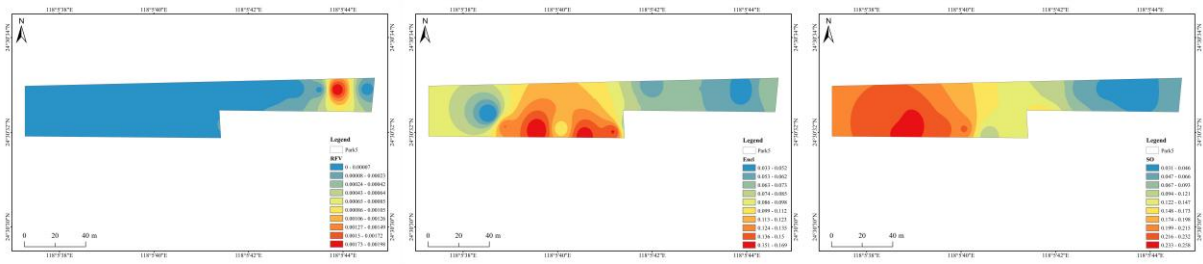


Fig. 8. Medium-potential representation of the internal RFV, Encl, and SO spatial distribution heat maps in Park 5.

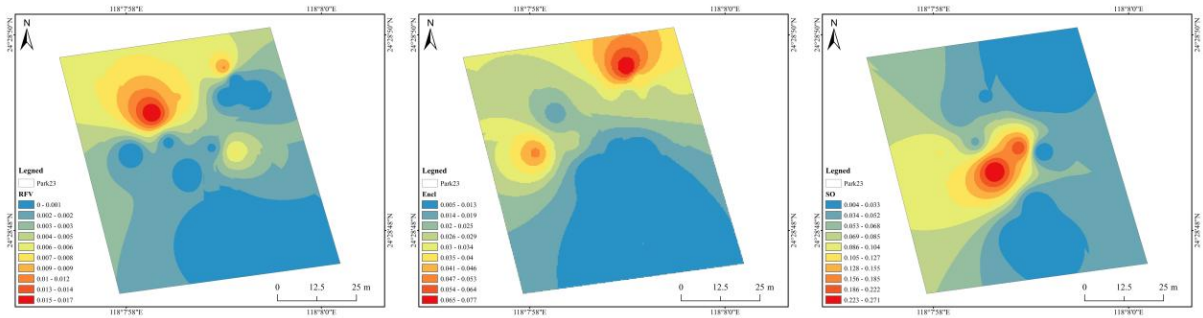


Fig. 9. Low-quality representation of the internal RFV, Encl, and SO spatial distribution heat maps in Park 23.

substantially increasing fall risk. This oppressive visual atmosphere constitutes the primary factor underlying Park 23's low evaluation score.

DISCUSSION

WEIGHTING LOGIC FOR CORE INDICATORS: PRIORITIZING FUNCTION IN AGE-FRIENDLY DESIGN

Coefficient of variation (CV) analysis reveals that RFV, Encl, and SO collectively account for 87% of the total assigned weight. It is important to note that CV weights quantify relative dispersion; thus, this high proportion reflects the extreme spatial heterogeneity of these features rather than their direct explanatory power or explained variance. Specifically, the very high weight assigned to RFV (37.6%) is strongly influenced by its near-zero mean and sparse spatial distribution across the parks. Nevertheless, this high variability highlights that functionality and perceived safety are the most inconsistently provided features in the current pocket park supply – a gap that is particularly consequential for older adults, for whom resting feasibility, security, and clear environmental perception are core requirements (Van Puyvelde *et al.*, 2023).

Contrary to younger adults' preference for secluded spaces, older adults favor environments that are

bright and visually controllable. The uneven provision of RFV further underscores the practical importance of visual affordance: if seating or activity facilities are not immediately visible upon entry, older adults – whose visual and locomotor capacities are often in decline – show a markedly reduced willingness to linger. Concurrently, the significant effects of Encl and SO is consistent with the applicability of Prospect-Refuge Theory to age-friendly design: older adults require moderate enclosure for shelter (Encl) yet desire open sky views (SO) to ensure adequate lighting and environmental surveillance (El-Metwally *et al.*, 2021). Therefore, the OAVQ-I index transcends its role as a purely visual evaluation tool, instead capturing pocket parks' efficacy in supporting older adults' complete behavioral chain – from safe entry through clear positioning to a comfortable stay.

SYNERGISTIC AND ANTAGONISTIC MECHANISMS AMONG INDICATORS: DETERMINANTS OF SPATIAL QUALITY

The Synergy Effect of Spatial Configuration

The high-quality park (Park 3) demonstrates that superior age-friendly environments emerge from the efficient synergy of core indicators. Although its mean RFV across the entire site is not exceptional, the spatial heat map reveals highly efficient configuration.

At rest and recreation nodes where older adults primarily congregate, high RFV, moderate Encl, and high SO converge to form a positive overlay. This configuration aligns closely with Appleton's Prospect-Refuge theory: high SO furnishes the visual clarity and illumination required for prospect; moderate Encl establishes the psychological safety boundary essential for refuge; and high RFV serves as a behavioral cue. The precise co-location and mutual reinforcement of these three elements render Park 3 the most frequented active space among older adults.

The Antagonistic Effect of Ecological Traps

The medium-quality park (Park 5) exposes the prevalent "green-only" fallacy in contemporary pocket park design, wherein natural elements (GVR) may conflict with age-friendly functional indicators (RFV, SO). Park 5 exhibits exceptionally high green visibility (GVR), yet its heat map reveals a global minimum for RFV and locally anomalous Encl values. This pattern indicates that dense, unpruned vegetation – while ecologically abundant – functions as visual interference. The impenetrable mid- and understory shrubbery not only obscures seating (reducing RFV to negligible levels) but also obstructs sightlines and daylight, yielding low SO and excessive safety blind spots within Encl. Here, ecological (GVR) and functional (RFV) indicators exhibit negative cancellation: despite superior greening, the absence of core service functions constrains overall quality to medium levels.

Systemic Collapse of Negative Indicators

The low-quality park (Park 23) illustrates systemic quality degradation when all three core indicators fail concurrently. Its heat map exhibits extreme co-directional negative feedback: total absence of facilities (RFV blindness), near-zero visibility (SO < 0.01), and boundary chaos (Encl). This pattern corroborates the "shortcoming effect" posited by the OAVQ-I framework. In Park 23, extreme shading (low SO) intensifies spatial gloom, while facility absence (zero RFV) strips the site of its social function as a park. The convergence of low indicator values generates vicious resonance, causing older adults to perceive this space as degenerating from a resting place into a negative, potentially hazardous thoroughfare.

INVERTED U-SHAPED THRESHOLD EFFECTS OF VISUAL INDICATORS AND PROSPECTS FOR NONLINEAR EVALUATION MODELS

While the OAVQ-I model employed linear normalization to successfully identify core variables, analyses of typical cases – such as the high GVR trap and high Encl blind area in Park 5 – reveal significant nonlinear relationships or threshold effects between specific visual indicators and elderly spatial preferences.

Linear models struggle to capture the negative impacts of excessive environmental elements. Specifically, the contributions of green view ratio (GVR) and enclosure degree (Encl) to spatial quality follow inverted U-shaped curves:

For GVR, ecological benefits and visual soothing effects peak within the moderate range of 0.3–0.5. However, when GVR exceeds a threshold (e.g., >0.6), dense vegetation begins to obstruct recreational facilities (reducing RFV) and obscure skylight (reducing SO), causing the curve slope to shift from positive to negative, as observed in Park 5.

For Encl, moderate values (approximately 0.1) provide necessary boundary definition and perceived protection. However, at extreme values (e.g., 0.464 at ID 338 in Park 5), spaces transform into closed dead-ends lacking natural surveillance, triggering heightened fear of crime.

Therefore, to more accurately reflect accessibility preferences, future OAVQ-I model optimizations should incorporate threshold-based nonlinear transformations. Gaussian functions or piecewise penalty functions could reconstruct GVR and Encl metrics by establishing an "optimal moderate range" within which index scores reach maximum values. Scores would then exhibit nonlinear decay when values fall below the lower limit or exceed the upper limit. This nonlinear mathematical refinement would effectively quantify the "antagonistic effects" identified in this study's micro-case analyses, providing more rigorous mathematical foundations for precise accessibility measurement.

SHIFTING THE EVALUATIVE LENS: THE ENDOGENOUS ADVANTAGES OF PANORAMIC IMAGING

Compared with conventional macro-scale assessments based on street-view imagery, the panoramic image collection method employed in this study offers distinct advantages for micro-scale evaluation of

pocket parks. Street-view images capture only street frontages and cannot penetrate internal pathways, understory spaces, or peripheral corners.

Our findings reveal marked spatial heterogeneity in visual quality within these parks. For instance, although Park 5 exhibits favorable overall greenness, it contains extreme visual blind spots that remain undetectable through street-view analysis alone. The OAVQ-I evaluation framework, grounded in panoramic imagery, precisely captures variations in light and shadow, facility occlusion relationships, and perceived enclosure from a ground-level perspective – thereby furnishing accurate diagnostic support for refined, age-friendly micro-scale interventions.

PLANNING AND DESIGN INSIGHTS

Based on these findings, future renovations of age-friendly pocket parks should transition from conventional approaches focused on increasing construction volume toward comprehensive visual optimization of existing spaces.

Vegetation Management. Blind pursuit of high green coverage should be avoided, and the shading effects of vegetation minimized. For parks resembling Type 5 – characterized by high green coverage yet low overall quality – continuous planting should be discontinued in favor of strategic shrub pruning in open areas. Specific measures include removing mid-story shrubs (0.6–1.5 m in height) that obstruct sightlines, thereby opening visual corridors and improving SO and RFV while mitigating risks associated with excessive vegetation density.

Visual Focus Mechanisms. Drawing upon the successful model of Park 3, designers need not distribute facilities uniformly throughout the site. Instead, high-RFV visual anchors can be established in core areas through chromatic contrast (e.g., orange seating) and concentrated layouts, thereby enhancing facility discoverability.

Mandatory Lighting Standards. Given the substantial weight of SO in the evaluation framework, light environment quality in wooded areas should be incorporated as a mandatory criterion in age-friendly facility acceptance protocols. For enclosed green spaces resembling Park 23, sky openness (SO) in primary activity areas must exceed a defined threshold (e.g., >0.15) to reduce fall risks and promote psychological well-being among older adults.

LIMITATIONS AND PROSPECTS

Although this study has established an elderly-friendly visual quality evaluation system based on

panoramic images (OAVQ-I) and yielded valuable findings, several limitations remain to be addressed in future research:

First, the sample size requires expansion to enhance generalizability. The empirical sample focused on 29 pocket parks within Xiamen Island, which effectively represents the spatial characteristics of subtropical coastal high-density urban areas. However, plant community structures and elderly-friendly facility configurations in pocket parks may vary significantly across different climate zones (e.g., cold northern regions) and urban morphologies. Future research should conduct cross-regional, large-scale comparative analyses to validate and refine the universality of the OAVQ-I evaluation model.

Second, the panoramic data collection method may introduce sampling bias. This study employed discrete static sampling points along primary pathways and activity nodes to characterize the park's visual environment. While this approach covers core activity areas, it may not adequately capture the continuous dynamic visual experience of elderly visitors during their ambulatory activities, and may overlook visual features in secluded areas. Future studies could incorporate continuous video sampling or denser grid-based sampling methods to improve spatial data resolution and completeness.

Third, the OAVQ-I lacks independent perceptual validation. The objective evaluation indices developed in this study are primarily grounded in environmental behavioral theories, such as "prospect-refuge" theory, deriving quality scores through quantification of physical environmental parameters without independent psychophysical or perceptual validation from the target demographic. Future investigations should integrate "objective measurement" with "subjective perception" by employing questionnaires, eye-tracking experiments, and portable physiological sensors (e.g., galvanic skin response, heart rate variability) to conduct cross-validation and elucidate the causal mechanisms linking objective indicators to actual psychological and physiological health benefits for the elderly.

Fourth, the calculation of panoramic pixel-area ratios requires consideration of spherical projection geometry. The current methodology calculates indicators based directly on pixel proportions from equirectangular projections. This approach inevitably introduces geometric distortion, overestimating areas near the zenith (SO) and nadir (WSR). Future research should apply solid angle weighting or reproject images to cubemaps prior to pixel calculation to rigorously account for these spherical distortions.

Fifth, although our semantic segmentation model achieved high global accuracy, the absence of reported quantitative class-specific intersection-over-union (IoU) metrics – particularly for ultra-small classes like rest facilities – limits the precise assessment of the model's boundary-level segmentation performance for these micro-elements. Future work should systematically report class-specific metrics to further validate algorithmic robustness.

Finally, seasonal dynamics of the visual environment were not considered. Data collection in this study was confined to the summer season, thereby failing to account for the dynamic effects of plant phenological changes (e.g., deciduous tree leaf senescence in winter) on high-weight indicators such as Green View Rate (GVR) and Sky Openness (SO). Future research should implement long-term longitudinal monitoring to develop dynamic evaluation models for visual quality across different seasons.

CONCLUSION

This study examined 29 pocket parks on Xiamen Island, utilizing panoramic imagery captured from older adults' vantage points to develop a spatial visual quality assessment framework for age-friendly pocket parks. Through semantic segmentation, six key visual indicators were quantified: green view index (GVI), natural element diversity, sky openness, spatial enclosure, recreational facility visibility, and walkable space ratio. The coefficient of variation method was employed to construct the Older Adult-friendly Visual Quality Index (OAVQ-I), systematically characterizing the overall levels and spatial differentiation of visual quality within high-density built environments.

The results indicate that while baseline exposure to natural elements across Xiamen Island's pocket parks is adequate, substantial heterogeneity exists in age-friendly visual quality, with high-quality spaces exhibiting distinct clustering patterns. Composite index analysis reveals that facility visibility, sky openness, and spatial enclosure serve as core determinants of age-friendly visual quality, demonstrating significantly greater explanatory power than conventional natural exposure metrics such as green coverage. This suggests that within micro-scale public green spaces, spatial configuration and functional affordances serve as critical physical proxies that theoretically shape older adults' environmental perception and behavioral potential.

From a spatial perspective, high-quality pocket parks do not merely depend on elevated green coverage or facility density; rather, they achieve quality through

strategic organization of visual elements, enhanced functional visibility at key activity nodes, and balanced openness-enclosure ratios, thereby forming coherent, legible, and secure environmental structures. Conversely, low-quality parks typically suffer from obscured facilities, inadequate illumination, or ambiguous spatial boundaries, failing to effectively support older adults' needs for rest, social interaction, and daily recreation.

This research advances the evaluative paradigm for pocket park visual quality from an older adult perspective, validates the applicability of panoramic imagery and deep learning techniques at the micro-green space scale, and furnishes quantifiable evidence for the renovation and optimization of existing pocket parks in high-density urban contexts. Future studies should integrate behavioral data and subjective perception surveys to elucidate causal relationships between visual quality and actual usage patterns, and test the transferability and robustness of this methodological framework across diverse urban and climatic contexts.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data involved in this research is quite extensive. If necessary, we can provide it according to your requirements. The data are available from the corresponding author on reasonable request.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE MANUSCRIPT PREPARATION PROCESS

During the preparation of this work the author(s) used Google Gemini tool in order to polish the article in English and check for spelling errors. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

ETHICS DECLARATIONS

This study was approved by the Ethics Committee on March 7, 2024, with the approval number 20240307032. We confirm that the participants had given their informed consent before participating in the study.

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