Equity-Oriented Optimisation of Public Space Supply-Demand in Ageing Communities: A Behavioural Perspective on Elderly Residents

Ruotong Zhang
College of Architecture and Urban Planning, Tongji University
2210254@tongji.edu.cn

Yi Wang
College of Architecture and Urban Planning, Tongji University
wangyicaup@tongji.edu.cn

Zhongjie Lin
Department of City and Regional Planning, Stuart Weitzman School of Design, University of Pennsylvania
zlin@design.upenn.edu

Abstract
China's urban renewal reveals persistent mismatches between formal public spaces and the heterogeneous behavioural needs of an ageing population. Employing a Multi-Group Huff Three-Step Floating Catchment Area model, this study quantifies age-stratified accessibility in Shanghai's Yinhang community, where elderly residents constitute 48% of the population (n = 1,016). Incorporating subgroup-specific walking distances and visitation frequencies demonstrates that conventional single-group models overestimate accessibility in 70% of residential compounds, disproportionately disadvantaging the oldest-old. Low formal accessibility significantly predicts the emergence of informal gathering nodes, indicating a compensatory bottom-up mechanism. Integrating behavioural heterogeneity and informal spatial practices into urban planning frameworks can thus enhance equity and efficiency in public-space provision for rapidly ageing cities.

Keywords: Two-step floating catchment area; Improved model; Equity; Accessibility

1. Introduction

The global demographic transition towards an ageing society is accelerating, with the proportion of individuals aged 60 and above projected to increase from 12% in 2020 to 22% by 2050 (World Health Organisation, 2024). China exemplifies this trend, with its elderly population expected to reach 39.9% by 2050, including a significant proportion (10.5%) aged 80 and above (Textor, 2023). As ageing progresses, the mobility of elderly residents declines, leading to a growing reliance on proximate public spaces within communities for daily activities (Wang, 2009) Informal public spaces, often spontaneously formed near residential entrances, small shops, and temporary structures, serve as critical everyday venues for elderly residents due to their proximity, familiarity, and ease of access.

Despite this, existing planning studies predominantly focus on formal public spaces, such as community parks and street green spaces, and often neglect the functional significance of informal public spaces. Moreover, current planning frameworks tend to generalise elderly residents as a homogenous group, failing to acknowledge behavioural distinctions across age cohorts. This homogenisation results in a spatial mismatch between standardised public space configurations and the differentiated needs of elderly residents, particularly the oldest-old. This leads to the underutilisation of formal spaces and the growing reliance on informal alternatives.

The Two-Step Floating Catchment Area (2SFCA) method has become a prominent tool for measuring public space accessibility, particularly in health care, green infrastructure, and elderly care (Tao and Cheng, 2016). However, conventional 2SFCA models assume uniform behavioural characteristics, ignoring variations in walking range, activity frequency, and spatial preference across elderly subgroups. This study introduces an enhanced model (Song, Kong and Cheng, 2024), the Multi-Group Huff Three-Step Floating Catchment Area (MGH3SFCA), incorporating age-specific behavioural parameters to overcome the limitations of conventional accessibility measurements. The objectives are threefold:
(1) Quantify behavioural differences in space usage across elderly age groups;
(2) Assess the impact of age-differentiated behaviours on accessibility measurements;

(3) Examine how accessibility deficits contribute to the emergence of informal public spaces.

2. Materials and Methods

2.1 Model Framework

The proposed MGH3SFCA model introduces three principal improvements to the conventional two-step floating catchment area (2SFCA) method. First, it incorporates a Gaussian distance-decay function (Liu, Chen, Xiang et al., 2024) to reflect the declining likelihood of accessing a facility as travel distance increases. Second, it employs the Huff probability model (Luo, 2014) to account for competitive interactions among alternative public spaces. Third, the model integrates age-specific behavioural parameters, including activity frequency and walking distance, and applies differentiated search radii according to the spatial scale of public space supply (Zhang et al., 2019). Larger-scale facilities are assumed to serve multiple residential clusters, whereas smaller spaces primarily cater to the immediate vicinity. The model operates in the following three steps.

(1) Estimating the Probability of Visiting Public Spaces

This step defines public space j and residential compound i as supply and demand nodes. Their geographic centroids are extracted for spatial calculations. The probability that residents in unit i will visit public space j is denoted as $\mathrm{Huff_{ij}}\mathrm{Huff_{ij}}$, calculated using Equation (1). Specifically, S_jS_j denotes the area of public space j, $d_{ij}d_{ij}$ represents the network distance between units i and j, and $G(d_{ij}, d_0)G(d_{ij}, d_0)$corresponds to the Gaussian distance-decay function defined in Equation (2).

$$\mathrm{Huff_{ij}} = \frac{S_j G(d_{ij}, d_0)}{\sum_{k\in\{d_{kj}\le d_0\}} S_k\, G(d_{kj}, d_0)} \quad (1)$$

$$G(d_{ij}, d_0) = \frac{e^{-\frac{1}{2}\times\left(\frac{d_{ij}}{d_0}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}} \quad (d_{ij} < d_0) \quad (2)$$

(2) Calculating the Supply-to-Demand Ratios

A first-step search is performed around each public space j within a predefined distance threshold $d_{0*}d_{0*}$. The supply-to-demand ratio R_jR_j is calculated using Equation (3), representing the relationship between the facility's supply capacity and the total weighted demand from elderly residents within its catchment area. Specifically, P_kP_k indicates the older adult population of a given age group in residential compound k, $f_{kj}f_{kj}$ reflects the frequency coefficient for visits from k to j, and $\mathrm{Huff_{kj}}\mathrm{Huff_{kj}}$ denotes the visit probability. These parameters jointly determine the composite demand weight for space j.

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\le d_{0*}\}} \mathrm{Huff_{kj}}\, f_{kj} P_k} \quad (3)$$

(3) Assessing Accessibility by Age Group

A second-step search is conducted around each residential compound i within the same distance threshold d_0d_0. Using the calculated supply-to-demand ratio, the age-specific accessibility (A_iA_i) of elderly residents in unit i to public space j is determined via Equation (4).To capture behavioural heterogeneity, the older adults population P_kP_k in each residential compound is divided into three subgroups: young-old $P_{kM1}P_{kM1}$, middle-old $P_{kM2}P_{kM2}$, and oldest-old $P_{kM3}P_{kM3}$. Group-specific accessibility scores are first computed and then aggregated into a composite multi-group accessibility index ($A_{i(multi-group)}A_{i(multi-group)}$) for each residential compound through weighted integration, as outlined in Equation (5).

$$A_i = \sum_{j \in \{d_{ij} \le d_0\}} Huff_{ij}\, G(d_{ij}, d_0) R_j \quad (4)$$

$$A_{i(multi-group)} = \frac{\sum_{M_1}^{M_n} A_{iM_n} f_{kj(Mn)} P_{kM_n}}{\sum_{M_1}^{M_n} f_{kj(Mn)} P_{kM_n}} \quad (5)$$

2.2 Study Area

Yinhang, located in the northeastern sector of Shanghai's Yangpu District, is the study site. Spanning 7.98 km², the community hosts approximately 194,100 residents, with nearly 47.7% of the population aged 60 or above. Among them, the proportion of elderly residents in poor health reaches 12.6%, compared to the municipal average of 9.7%; similarly, the share of functionally dependent elderly (i.e., unable to care for themselves) exceeds 4.7%, significantly higher than the Shanghai average of 3.2% (National Bureau of Statistics of China, 2021). These figures indicate that Yinhang exhibits a higher-than-average burden of ageing-related health limitations. The community comprises 66 residential compounds and a diverse public space system, including formally planned and spontaneously formed informal public spaces (Figure 1).

Figure 1. Location of Yinhang Community in Shanghai

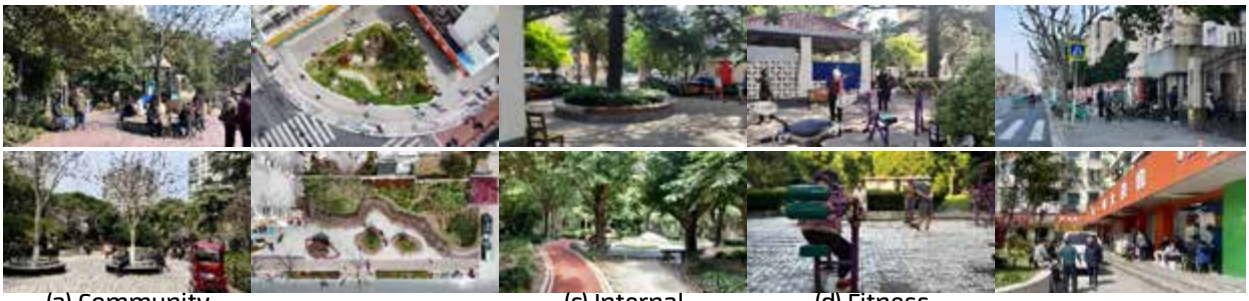
2.3 Data Collection and Processing

(1) Elderly Residents' Demand

Residential population data directly reflect the spatial distribution and quantity of potential public space users, while age structure provides a critical demographic basis for evaluating differentiated deman (Wang, Wu, Gao et al., 2021). The smallest unit of analysis is the "residential compound" ('xiaoqu'), a prevalent housing type in Chinese cities. Population data were derived from the Seventh National Population Census of China (2020–2021) and were classified into three age cohorts: young-old (60–69 years), middle-old (70–79 years), and oldest-old (80 years and above). Walking distances were defined by observed gait speeds: 5-, 10-, and 15-minute walks equate to 180–300 m, 360–600 m, and 540–900 m, respectively. These demographic layers were integrated with spatial data using ArcGIS to support the demand-side component of the model.

(2) Public Space Supply

Public spaces within a 500-m radius of the Yinhang community were identified using a combined approach that included point-of-interest (POI) annotation from online maps and on-site field investigations conducted in March 2024. A total of 95 formal public spaces were delineated and classified into four types according to their functional role and designated service radius: community parks (J1), street green spaces (J2), internal parks (J3), and fitness stations (J4). The assignment of service radii, ranging from 300 to 1000 meters, followed the guidelines outlined in China's Urban Green Space Planning Standards (GB/T 51346–2019). All spatial locations were geocoded in ArcGIS to construct the supply-side spatial database. Additionally, 24 informal public spaces were identified through a structured, week-long behavioural observation period. These locations exhibited consistent patterns of elderly gathering and were equipped with basic amenities such as benches, shade structures, or handrails. Based on these characteristics, they were defined as Spontaneous spaces (J5) and incorporated into the model's supply-side dataset. (Figure 2)



(a) Community Park (b) Street Green Space (c) Internal Park (d) Fitness Point (e) Spontaneous Space

Figure 2. Examples of Public Space Types (J1–J5

(3) Behavioural Data

A structured questionnaire survey targeting residents aged 60 and above was conducted in Yinhang community from March to July 2024. The survey was administered during clear daytime periods (08:00–18:00) across all days of the week to account for variability in behavioural patterns. The questionnaire comprised two parts: personal demographics (age, health status, and mobility condition) and public space usage behaviours (frequency, duration, type of activity, and mode of travel). Only respondents who reported walking directly from home to a public space were included in the modelling. Actual walking distances were computed using the Origin-Destination (OD) matrix function in ArcGIS. The resulting dataset informed the behavioural weights used in the MGH3SFCA model, particularly in estimating frequency coefficients and mobility thresholds across age groups.

3. Results

3.1 Age-Specific Differences in Behavioural Activities

A total of 1,525 questionnaires were distributed, yielding 1,405 valid responses. Walking emerged as the dominant mode of travel among elderly residents (84.9%), followed by non-motorised vehicles (11.5%) and public buses (0.9%). Among respondents, 87.6% reported walking directly from home to their activity destinations, while only 8.3% indicated detouring through other activities. The final sample included 1,049 elderly residents who reported walking directly to a public space. (Table 1)

Table 1. Age Distribution of Elderly Residents by Public Space Type

	Young-old	Middle-old	Oldest-old	Total
Community Park (J1)	136 (37%)	172 (47%)	57 (16%)	365
Street Green Space (J2)	129 (46%)	94 (34%)	56 (20%)	279
Internal Park (J3)	81 (43%)	71 (38%)	37 (20%)	189
Fitness Point (J4)	44 (53%)	20 (24%)	19 (23%)	83
Spontaneous Space (J5)	54 (41%)	52 (39%)	27 (20%)	133
Total	444	409	196	1049

Note: Percentages in parentheses represent the proportion of each age group within the corresponding public space type.

Chi-square tests (Table 2) revealed significant age-related differences in health status and mobility. The proportion of individuals with chronic illness increased from 18% in the young-old group to 36% in the oldest-old group ($p < 0.01$). Meanwhile, the share of residents with unimpaired walking ability dropped from 91% to 53% across the same age ($p < 0.01$). These age-related health and mobility declines significantly influence public space use patterns and walking range.

Table 2. Chi-Square Test Results of Behavioural Characteristics by Age Group

	Young-old	Middle-old	Oldest-old	Total	χ^2	p
Health status						
With chronic disease	18%	33%	36%	27%	35.928	0.000**
Without chronic disease	82%	67%	64%	73%		
Mobility status						
Normal walking	91%	78%	53%	79%		
Slow walking	9%	20%	33%	17%	143.622	0.000**
Cane assistance	1%	1%	12%	3%		
Wheelchair assistance	0%	1%	3%	1%		
Walking distance (m)						
< 213.39	24%	27%	19%	24%		
213.39–322.76	20%	28%	29%	25%	20.334	0.002**
322.76–620.43	26%	25%	27%	26%		
> 620.43	30%	20%	26%	25%		
Visit frequency						
Occasionally	3%	2%	1%	2%		
Once a week	2%	1%	2%	2%		
Multiple times a week	23%	15%	15%	18%	20.435	0.025*
Once a day	48%	52%	60%	52%		
Twice a day	20%	25%	19%	22%		
Three times a day	4%	4%	3%	4%		
Activity intensity						
Low	50%	44%	58%	49%		
Medium	48%	54%	41%	49%	20.64	0.008**
High	2%	1%	1%	2%		
Activity status						
Group activity	42%	41%	45%	42%	0.838	0.658
Independent interaction	58%	59%	55%	58%		
Single activity duration (h)						

< 0.33	21%	24%	21%	22%	3.13	0.792
0.33–0.50	12%	11%	9%	11%		
0.50–0.67	23%	23%	22%	23%		
> 0.67	45%	43%	48%	45%		
Daily activity duration (h)						
< 1.00	45%	43%	48%	45%	3.13	0.792
1.00–1.50	12%	11%	9%	11%		
1.50–2.00	23%	23%	22%	23%		
> 2.00	21%	24%	21%	22%		

Note: * p < 0.05; ** p < 0.01. Significant results are marked accordingly in the respective rows.

(1) Age Differences in Walking Distances

Figures 3 and 4 present the distribution of walking distances and visit frequencies across various types of public spaces, stratified by the three age groups of the elderly. The young-old group exhibits the strongest walking ability, with a broad range of spatial activity across all space types. In particular, the median walking distances to community parks (J1) and street green spaces (J2) range from 400 to 600 metres, with some individuals walking more than 1,000 metres, indicating extensive mobility. In contrast, the middle-old and oldest-old groups show a progressive decline in walking ability. Their median walking distances are generally shorter, especially in internal parks (J3) and fitness stations (J4), where most visits occur within a 300-metre radius. This reduction is most pronounced among the oldest-old, whose median distances fall below 300 metres across all space types, reflecting a high dependence on nearby spaces. Notably, in spontaneous public spaces (J5), the differences among age groups are much smaller. This suggests that informal public spaces are significant for the oldest-old, as their proximity effectively accommodates the mobility limitations of this subgroup.

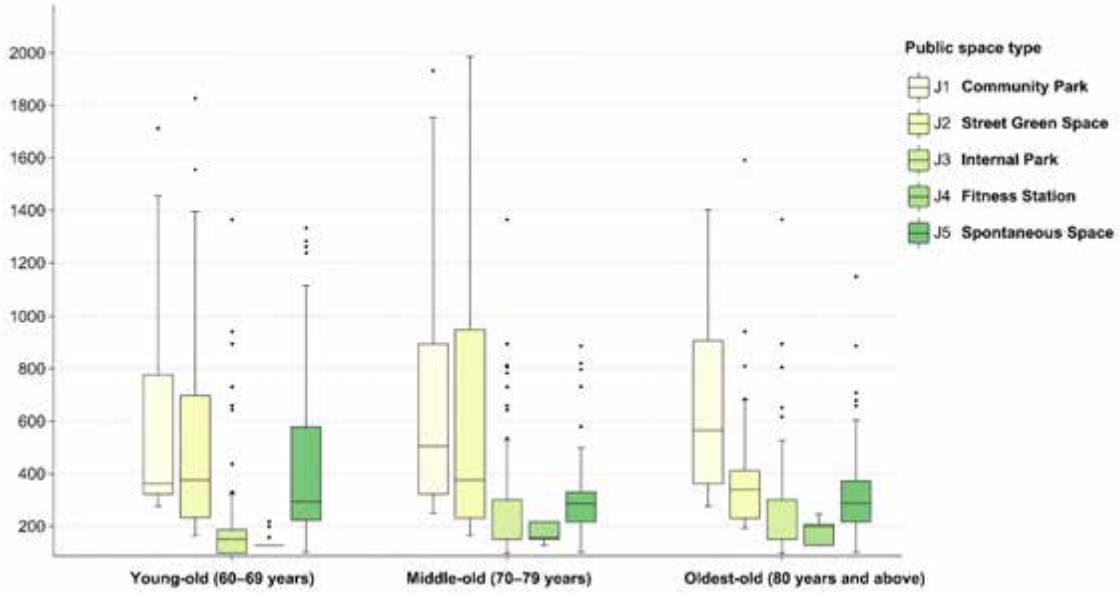


Figure 3. Walking Distance to Public Spaces by Age Group

(2) Age Differences in Visiting Frequency

Regarding visit frequency, community parks (J1) and street green spaces (J2) exhibit relatively stable usage across all age groups, with an average of once per day. Internal parks (J3) and fitness stations (J4) exhibit a moderate decline in visitation among the middle-old and oldest-old groups, possibly due to smaller spatial scale or higher use thresholds. In contrast, spontaneous public spaces (J5) maintain consistently high visitation frequencies

across all age groups. This trend is particularly pronounced among the oldest-old, with a median visit frequency of one to two times per day, and some individuals reporting up to three visits per day. These findings highlight residents' substantial reliance on informal public spaces, particularly among those with mobility constraints. In summary, walking distance and visit frequency demonstrate age-related stratification and marked differences across space types. Formal public spaces (J1–J4) are more likely to attract the young-old for medium- to long-distance, low-frequency use. In contrast, informal public spaces (J5) support high-frequency, short-distance daily activities among the oldest-old due to their proximity, flexibility, and accessibility.

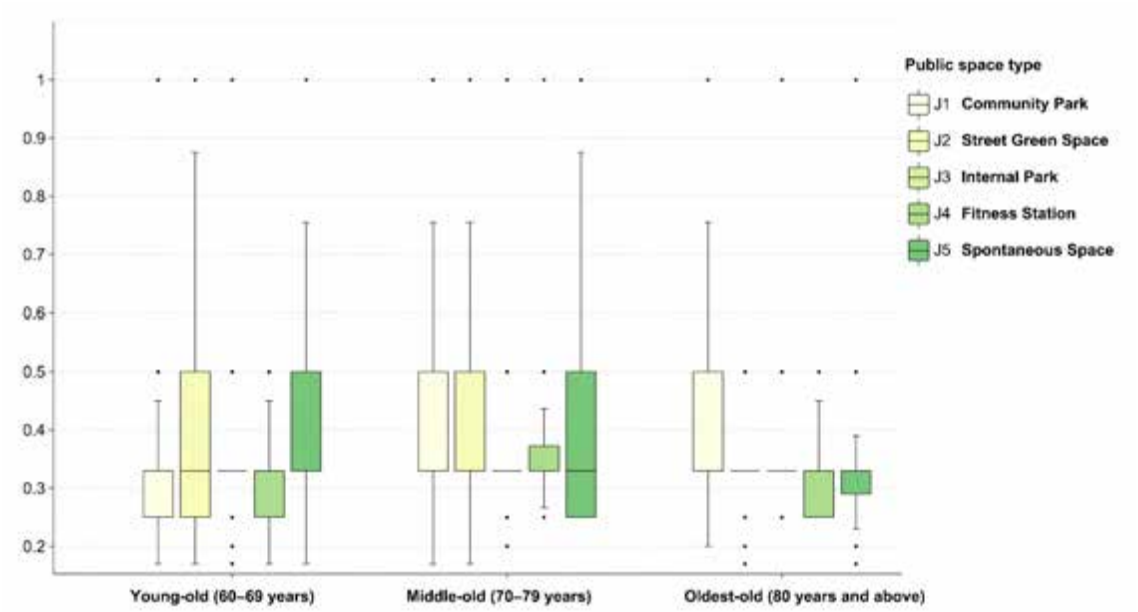
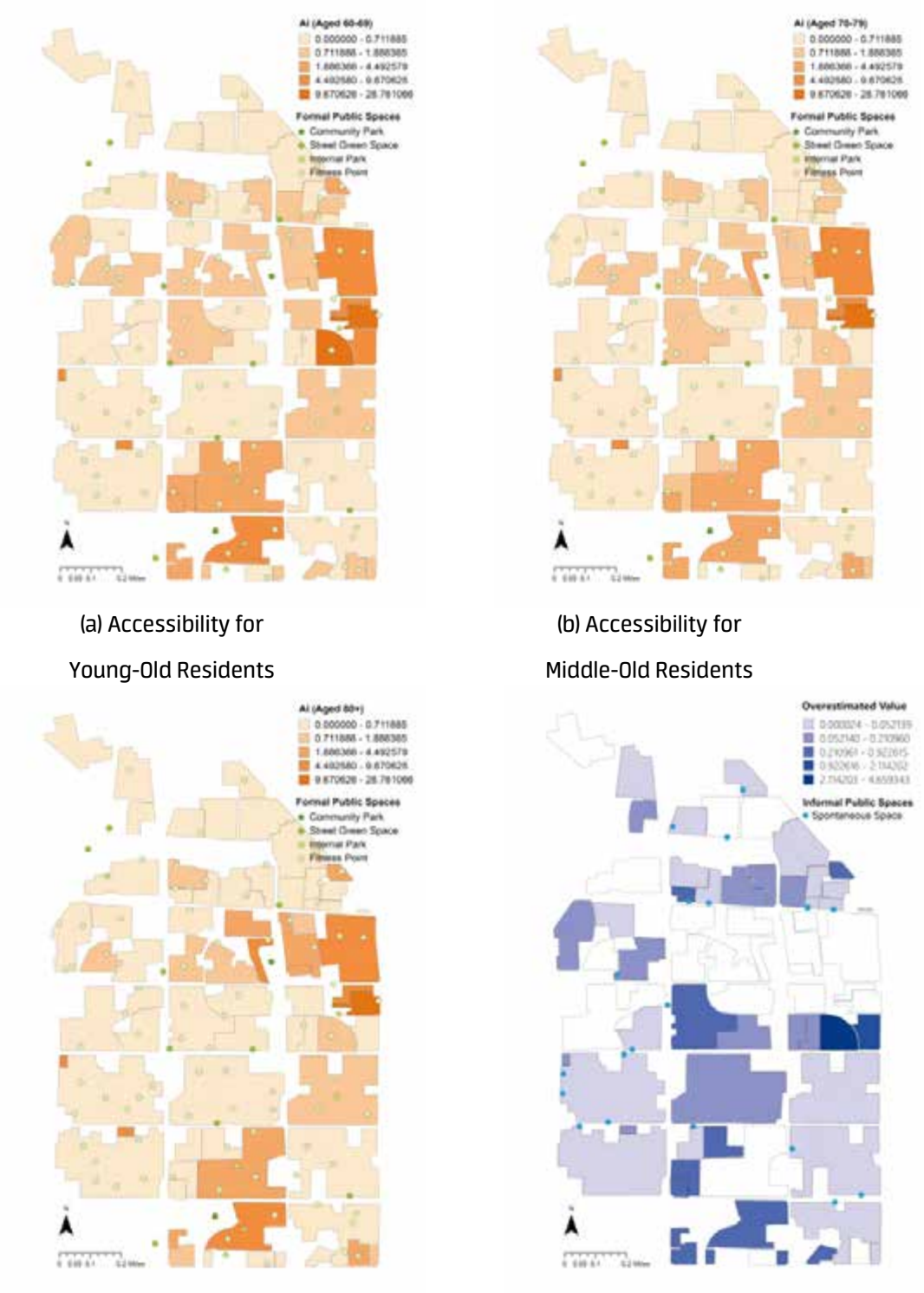


Figure 4. Visit Frequency to Public Space Types by Age Group

Note: Visit frequency codes: 0.17 = occasional; 0.20 = weekly; 0.25 = several times/week; 0.33 = daily; 0.50 = twice/day; 1.00 = three times/day.

3.2 Accessibility Results of Single vs Multi-Group Models

Based on MGH3SFCA model outputs, public space accessibility was calculated for each age group across residential compounds. Values were categorised into five levels using ArcGIS natural breaks: very high, high, medium, low, and very low (Figure 5a–5c). Results show that the single-group model consistently overestimates accessibility compared to the age-specific model. Around 70% of residential compounds exhibited overestimation, with an average margin of 15.9% (Figure 5d). This disparity is most evident in units rated 'very high' by conventional models, where the oldest-old residents still face limited effective access. The findings highlight the importance of incorporating intra-group behavioural variation in accessibility planning.



(a) Accessibility for Young-Old Residents

(b) Accessibility for Middle-Old Residents

(c) Accessibility for Oldest-Old Residents

(d) Spatial Distribution of Accessibility Overestimation

Figure 5. Multi-Group Accessibility Modelling Results

3.3 Correlation Analysis of Accessibility and Informal Public Space Distribution

In the Yinhang community, informal public spaces formed through the spontaneous gathering of elderly residents are predominantly located near the entrances of residential compounds, which have zero or low comprehensive accessibility, particularly in communities with a high proportion of residents aged 80 and above. For example, although Guohe No. 2 Community and Shiguang No. 2 Community are relatively limited in spatial scale, they effectively accommodate the needs of elderly residents for nearby social interaction and daily leisure activities. Moreover, even in communities with relatively well-organized formal public spaces, informal gatherings are often observed beneath the eaves of street-facing shops, such as those located at Lane 590 and Lane 296 on Yinhang Road. These spatial patterns indicate that elderly residents, particularly those in the oldest-old group, tend to choose locations with high pedestrian traffic and open visibility, such as traffic intersections or commercial frontages, to engage in social interaction activities, including conversation and chess. This behavioural preference reflects a conscious strategy to increase the likelihood of informal social encounters and to mitigate the sense of isolation often experienced in daily routines.

To further quantify the relationship between comprehensive accessibility and the distribution of informal public spaces, this study employed a binary logistic regression model to examine the correlation between accessibility levels and the presence or absence of informal public spaces, using residential compounds as the unit of analysis. Additionally, a negative binomial regression model was employed to examine the impact of accessibility on the number of informal public spaces. The results indicate a significant negative association between the comprehensive accessibility of elderly residents and the emergence of informal public spaces (Table 3). Specifically, for every 0.1 unit decrease in comprehensive accessibility, the probability of informal public space formation increases by approximately 24.6% (odds ratio = 0.059, p = 0.011), while the number of such spaces increases by roughly 20.4% (incidence rate ratio = 0.102, p = 0.011). These findings suggest that when formal public space provision fails to accommodate the behavioural capabilities of senior residents, they are more likely to create alternative spaces within the community spontaneously. This pattern reflects a spatial equity feedback mechanism, whereby informal public space formation emerges as a compensatory response to deficiencies in formal accessibility.

Table 3. Influence of Accessibility on Informal Public Space Formation

	Model 1: Presence (0/1)	Model 2: Count (Number)
Regression method	Logistic regression	Negative binomial regression
Exp(B)	0.059	0.102
95% CI	[0.007, 0.527]	[0.018, 0.595]
p-value	0.011*	0.011*
Sample size (n)	66	66
Model fit	McFadden R^2 = 0.316	Pearson χ^2/df = 0.570

Note: * p<0.05; ** p<0.01.Model 1 estimates the probability of informal public space presence; Model 2 estimates its quantity.

4. Discussion

4.1 Deficiencies in Conventional Accessibility Planning

With the accelerating ageing process, differences between younger-old and oldest-old residents can surpass those between elderly and non-elderly populations (Neugarten, 1974). Nevertheless, current urban planning often treats older adults as a single group, using average walking capacity to define service radii for public spaces, which fails to address the age-specific needs of this population. In Shanghai, the Beautiful Homes Three-Year Action Plan (2021–2023) was implemented as part of the broader 15-Minute Community Life Circle initiative, aiming to improve community environments through micro-scale renewal (Liu, Qian, Huang and Zhou, 2020). However, many newly built formal public spaces remain underutilised, while informal areas such as residential entrances and street-facing shopfronts attract frequent use by elderly residents.

Empirical findings further demonstrate that the walking distance of the oldest-old group is significantly shorter than that of the young-old. However, current planning practices overlook this disparity, resulting in a systematic overestimation of formal public space accessibility for the senior population. Moreover, formal public spaces often exhibit homogenisation in scale, spatial layout, and functional design, with limited adaptation to the specific needs of senior residents, such as provisions for short-distance resting or enhanced visual safety (Sun et al., 2020). This misalignment between spatial supply and actual behavioural demand drives elderly residents to frequent informal public spaces near residential entrances and street-facing shops. Variations in accessibility among different housing units primarily reflect disparities in the spatial provision of housing. In contrast, disparities among elderly age groups within the same unit reveal deeper issues related to equity in the allocation of public space.

4.2 Informal Public Space as a Behavioural Adaptation

The theory of everyday urbanism emphasises that the production of urban space is shaped not only by top-down planning and design but also by residents' routine behaviours and spatial practices. Informal public spaces emerge spontaneously through micro-scale actions by elderly residents, such as placing chairs or installing pergolas. These spatial practices complement formal spaces and reflect overlooked equity demands of elderly residents (Torres and Cao, 2019). The formation and spatial distribution of informal public spaces exhibit apparent regularities, with concentrations typically observed in highly accessible locations such as entrances of residential compounds and areas beneath the eaves of street-level shops. This spatial pattern is shaped by the combined influence of physiological limitations and psychological needs among elderly residents. Proximity to residential buildings ensures that these locations remain reachable even for individuals with reduced mobility. At the same time, such areas often offer open sightlines and steady pedestrian flows, which enhance the perceived safety of outdoor activities and provide opportunities for social interaction and incidental encounters with acquaintances, fulfilling essential psychological and social needs. In contrast, although physically open, marginal spaces such as street corners, the peripheries of enclosed green areas, or the backs of public facilities, are rarely used by elderly residents. These areas lack sufficient accessibility, visibility, and pedestrian presence, and are often devoid of environmental familiarity. These findings suggest that the formation and utilisation of informal public spaces are not solely determined by physical attributes, but reflect active spatial choices made by elderly individuals within the constraints of their physical capabilities. Such preferences underscore a perceived demand for environments that offer both safety and opportunities for social interaction.

4.3 Strategies for Integrating Informal Public Spaces into Planning Frameworks

Although formal public spaces can theoretically achieve optimal spatial allocation through rational planning and design, their implementation is often constrained by limited land availability and high construction costs. These constraints hinder formal spaces' ability to fully meet the diverse activity needs of senior residents, particularly in communities with high population ageing. In this context, informal public spaces serve an essential compensatory role due to their flexibility, convenience, and proximity to residential areas. With appropriate guidance and moderate planning intervention, these spontaneously formed spaces can be gradually integrated into the formal public space system. Such integration can effectively address the limitations of formal planning and enhance the overall equity and responsiveness of urban public space provision (Sikorska et al., 2020).

The strategic incorporation of small-scale public spaces at spontaneous gathering sites can effectively respond to the diverse needs of elderly residents in ageing communities where spatial resources are limited. First, modest physical improvements at residential entrances and exits, including surface paving, ground levelling, and installing seating, shading structures, and handrails, can transform these locations into formally accessible areas for rest and social interaction. Second, residual spaces beneath shop eaves can be utilised by providing simple benches or small activity platforms, thereby encouraging elderly residents to gather in a safe and orderly manner within the street environment. When immediate physical upgrades are not feasible, community-led services such as regular health consultations, social activities, or chess games can activate these spaces and incorporate them into routine community management. Through the coordinated advancement of physical

micro-renewal and service provision, informal public spaces can be gradually integrated into the broader public space system. This process not only addresses the differentiated needs of elderly residents across age groups but also improves spatial utilisation, promotes resident engagement, and enhances the overall quality of life in ageing communities.

5. Conclusion

This study highlights the importance of behavioural heterogeneity in assessing public space accessibility for elderly residents. The MGH3SFCA model, which integrates age-specific walking distances and activity frequencies, reveals that conventional approaches substantially overestimate accessibility. The spatial emergence of informal public spaces in low-accessibility areas further reflects bottom-up compensatory behaviours driven by unmet needs. Two policy implications can be drawn. First, accessibility models should differentiate between elderly subgroups to avoid systemic misestimations. Second, informal public spaces should be considered essential for ageing-supportive urban systems. Behaviour-sensitive modelling and inclusive spatial design collectively provide promising strategies for achieving more equitable and effective public space provision in ageing societies.

Acknowledgements

This study was completed during a one-year academic visit to the University of Pennsylvania. The authors are grateful for the academic support of the Stuart Weitzman School of Design and deeply appreciate the invaluable guidance and critical insights provided by Professor Zhongjie Lin.

References

Liu, L., Chen, Y., Xiang, H., Zhong, J., Zhou, P., Xiao, Y., Wang, L. and Sun, Y. (2024). Measuring and optimizing the spatial accessibility of primary health care in remote and rural areas: a case study of Liannan Yao Autonomous County in China. *BMC Health Services Research*, 24(1). doi:https://doi.org/10.1186/s12913-024-11556-1.

Liu, Q., Qian, Z., Huang, D. and Zhou, X. (2020). The Characteristics of Spatial Pattern Evolution and the Trend of the 15-Minute Life Circle. *Urban Planning Forum*, (06), pp.94–101. doi:https://doi.org/10.16361/j.upf.202006013..

Luo, J. (2014). Integrating the Huff Model and Floating Catchment Area Methods to Analyze Spatial Access to Healthcare Services. *Transactions in GIS*, 18(3), pp.436–448. doi:https://doi.org/10.1111/tgis.12096.

National Bureau of Statistics of China (2021). *Main Data of the Seventh National Population Census*. [online] Stats.gov.cn. Available at: https://www.stats.gov.cn/sj/pcsj/rkpc/d7c/.

Neugarten, B.L. (1974). Age Groups in American Society and the Rise of the Young-Old. *The ANNALS of the American Academy of Political and Social Science*, 415(1), pp.187–198. doi:https://doi.org/10.1177/000271627441500114.

Sikorska, D., Łaszkiewicz, E., Krauze, K. and Sikorski, P. (2020). The role of informal green spaces in reducing inequalities in urban green space availability to children and seniors. *Environmental Science & Policy*, 108. doi:https://doi.org/10.1016/j.envsci.2020.03.007.

Song, L., Kong, X. and Cheng, P. (2024). Supply-demand matching assessment of the public service facilities in 15-minute community life circle based on residents' behaviors. *Cities*, 144, pp.104637–104637. doi:https://doi.org/10.1016/j.cities.2023.104637.

Sun, X., Wang, L., Wang, F. and Soltani, S. (2020). Behaviors of seniors and impact of spatial form in small-scale public spaces in Chinese old city zones. *Cities*, 107, p.102894. doi:https://doi.org/10.1016/j.cities.2020.102894.

Tao, Z. and Cheng, Y. (2016). Research Progress of the two-step Floating Catchment Area Method and Extensions. *PROGRESS IN GEOGRAPHY*, 35(5), pp.589–599. doi:https://doi.org/10.18306/dlkxjz.2016.05.006.

Textor, C. (2023). *China: population share aged 60 and older until 2100*. [online] Statista. Available at: https://www.statista.com/statistics/251529/share-of-persons-aged-60-and-older-in-the-chinese-population/.

Torres, S. and Cao, X. (2019). Improving Care for Elders Who Prefer Informal public spaces to Age-Separated

Institutions and Health Care Settings. *Innovation in Aging*, 3(3). doi:https://doi.org/10.1093/geroni/igz019.

Wang, H., Wu, J., Gao, Y., Liu, L. and Yang, W. (2021). Spatial Fitness of Urban Public Resources and Population Distribution:Taking Shenzhen as an Example. *Acta Scientiarum Naturalium Universitatis Pekinensis*, 57(06), pp.1143–1152. doi:https://doi.org/10.13209/j.0479-8023.2021.088..

Wang, S. (2009). Urban Community Welfare Services in China:Low Availability and Development. *Jilin University Journal Social Sciences Edition*, 49(01), pp.133-139+160. doi:cnki:SUN:JLDB.0.2009-01-024.

World Health Organisation (2024). *Ageing and Health*. [online] World Health Organization. Available at: https://www.who.int/news-room/fact-sheets/detail/ageing-and-health.

Zhang, F., Li, D., Ahrentzen, S. and Zhang, J. (2019). Assessing spatial disparities of accessibility to community-based service resources for Chinese older adults based on travel behavior: A city-wide study of Nanjing, China. *Habitat International*, 88, p.101984. doi:https://doi.org/10.1016/j.habitatint.2019.05.003.