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Age-Friendly Street Construction: The Synergy of the Physical Environment in Old Urban Communities in Suzhou

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Abstract: Community streets play a crucial role in promoting healthy aging and encouraging active behaviors among older adults. This study focuses on two types of activities of older adults: walking and social interaction. We explored the relationship between physical environmental factors and different activity types using a multiple linear regression model. Eye-level green visibility (GSV_N) was used to represent the diversity of facilities (DF_N), while betweenness (AB_N) accounted for the mixed degree of functions (P_{Ni}), enhancing model stability. The results indicate that community environmental factors, both individually (R^2 = 0.390) and in combination (R^2 = 0.409), have significant effects on active behaviors. Notably, the combined variable model demonstrated greater stability. Moreover, the model's explanatory power for social interaction (R^2 = 0.567) was much higher than for walking behavior (R^2= 0.137), underscoring the stronger influence of combined variables on social engagement. The results suggest that creating age-friendly urban environments requires a holistic approach that improves infrastructure, green visibility, and functional diversity to promote both mobility and social interaction. These insights provide valuable guidance for designing inclusive urban spaces that support active aging.

Keywords: old urban community; streets; older adults; interaction effect; Suzhou

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1. Introduction

The global aging process is rapidly accelerating, posing significant challenges to housing, the environment, urban spatial structure, and economic growth; while also straining social security systems and urban sustainability [1]. As a result, promoting healthy aging, which aims to maximize healthy life expectancy (HALE), has become a crucial public health concern [2]. Healthy aging is influenced not only by individual lifestyle and behaviors but also by the surrounding environment [3]. Aging in place, where older adults continue to live in their own homes and communities, is considered a critical strategy for promoting healthy aging and building age-friendly environments [4]. The World Health Organization (WHO) highlights the importance of streets as essential spaces for local aging, as the active living behaviors of most older adults revolve around and depend on neighborhood streets [5]. This is particularly relevant in older urban communities, where limited opportunities for urban renewal mean that walking streets serve as critical spaces for both physical and social engagement, providing vital connectivity for aging populations [6,7]. Therefore, well-designed street environments are crucial for encouraging active living behaviors in older adults, supporting both their physical health and social well-being.

Active living behaviors, such as walking and cycling, as well as social interactions, are widely recognized for improving the physical and mental health of older adults [8]. Insufficient physical activity increases the risk of various diseases, including cancer, heart disease, stroke, hypertension, and diabetes by 20–30% in older adults [9,10]. However, global data from 76 countries show that 21.4% of adults remain physically inactive [11]. Walking is a cost-effective, convenient, and prevalent form of physical activity among older adults [12]. Beyond reducing the risk of diseases such as cancer and cardiovascular disease, and improving bone strength of older adults, walking also has a positive impact on mental health across older populations [13,14]. Many studies have regarded walking as a critical gauge of physical activity intensity among older adults. Moreover, social interaction plays a pivotal role in fostering healthy aging [15]. Increased social interaction among older adults mitigates feelings of isolation and reduces the risks associated with depression, anxiety, and chronic ailments [16]. Existing evidence depicts a positive correlation between the frequency of walking and social interaction [15,17], which is attributable to the potential provision of social support by walking companions. Hence, both walking behavior and social interaction are vital in ameliorating the physical and mental well-being of older adults and enhancing urban public health.

Walking and social interaction result from the interaction between individuals and their environment [12,18]. Neighborhood streets, which serve as key venues for activities such as walking and socializing among older adults [19], can be considered extensions of their homes; places where they regularly engage with neighbors and build new connections. In densely populated cities, particularly in China, streets play an even more vital role in fostering social interactions and physical activities among the elderly, thereby contributing significantly to their overall well-being [4,20]. Evidence shows that changes in community environmental factors have a more pronounced impact on the walking and social interaction of older adults compared to younger individuals [6]. Therefore, understanding and quantifying the influence of community street spaces on active behaviors, such as walking and social interaction, is crucial for promoting an active lifestyle among older adults.

On the one hand, the quality of the physical environment of streets, including both built and natural elements, directly impacts residents' preferences for walking [4,15]. Measurable aspects of physical environmental quality at the neighborhood street scale include walking conditions, infrastructure provisions, and natural environmental quality [21,22]. For instance, communities with better traffic services, such as greater sidewalk widths and intersection densities, tend to exhibit higher levels of walking activity [23,24]. The availability of amenities such as parks, fitness equipment, and recreational facilities can also enhance the walkability of streets [6]. Features such as greenery and landscape quality further influence residents' preferences for walking. On the other hand, previous studies confirm that beyond physical activities such as walking, the health benefits of community street environments for older adults extend to social interaction and other communal activities [12,25]. The utilization of physical environments at the community level, namely streets, is correlated with walking behavior and social interaction, highlighting the need to address differences in the impacts of environmental quality on the active behaviors of older adults.

Despite extensive research on the benefits of physical activity and social interaction for older adults, significant gaps remain in understanding how these behaviors are influenced by the unique characteristics of old urban communities, particularly in Eastern settings. Much of the existing literature has focused on modern urban environments and Western cultures, where infrastructure and community design may differ substantially from the older, densely populated urban areas commonly found in China and other Asian countries [12,24]. These older communities often face challenges such as narrow streets, aging infrastructure, and limited public spaces, which can impact the ability of older adults to engage in physical activities and social interactions [24]. Furthermore, while growing evidence highlights the importance of street environments for supporting active lifestyles, few studies have examined the interaction between physical environments and social behaviors in older populations living in these settings [23,26]. This lack of focused research creates a critical gap in knowledge, particularly regarding how spatial organization and environmental quality in old urban communities influence both walking behavior and social interaction among older adults. Addressing this gap is essential for developing age-friendly interventions that promote healthy aging in such environments.

Suzhou, renowned for its trade, commerce, and rich cultural heritage [26], has undergone significant urbanization since China's economic growth in the 1980s [27]. This transformation has led to the emergence of numerous old urban communities characterized by a construction age exceeding 40 years [28]. Typically located in the city center, these old urban communities boast high plot ratios and population densities [28]. However, their narrow streets and limited functionalities often fail to meet the evolving needs of contemporary residents, particularly older adults, for active living. Despite these challenges, Suzhou remains a well-preserved historical and tourist center celebrated for its classical gardens and vibrant local culture, making it a primary attraction for visitors. Striking a balance between preserving Suzhou's historic districts and implementing orderly urban renewal tailored to the needs of its aging population holds significant value. Therefore, efforts to quantify the physical environmental quality of community streets and to understand the walking behaviors and social interactions of older adults within these neighborhoods could promote healthy aging, boost local tourism, and stimulate economic growth [23].

The following specific research questions are addressed in the present investigation.

- What are the characteristics of walking behavior and social interaction among older adults in the streets of older communities?
- Are there differences in the relationships between the physical environmental factors of community streets and the walking behavior and social interaction of older adults? If so, in what aspects are these differences reflected?

Data on the environmental conditions of three community streets and the street activities of older adults were collected through on-site, non-participant observation. Statistical analysis was then applied to summarize the types of active travel and social interaction, and to identify differences in social participation.

2. Materials and Methods

2.1. Study Site

We focused on Suzhou (30°47′ to 32°02′ and 119°55′ to 121°20′), a pivotal city in the Yangtze River Delta Area and a crucial economic hub in China (Figure 1a). The permanent resident population of Suzhou reached 12.748 million in 2020, with the actual population reaching 16.1979 million by 2023 [29,30]. Since 1979, Suzhou's urban planners have faced the dual pressures of urban development and population aging. Communities built with government or institutional funding prior to the 2000 housing reforms [31] are typically defined as old urban communities. This study targeted three typical old urban communities within Suzhou's main urban area, each featuring a mix of low-rise, high-density housing. While the Erlangxiang community, located in Suzhou's ancient city district, features a traditional mix of residential complexes and alley-style housing, the Suyuannan and the Sanxiang communities consist of more modern residential complexes. Despite differences in their construction periods, all three communities share key characteristics, including compact layouts, insufficient infrastructure, and a reliance on internal or nearby urban facilities. Together, these communities represent the major old community types in Suzhou, making them highly relevant for this study.

As shown in Figure 1b, the sample sites included the Suyuannan community (with 110 walkable roads), Erlangxiang community (with 171 walkable roads), and Sanxiang community (with 138 walkable roads). The research scope was defined according to the administrative boundaries of communities or streets, encompassing all walkable roads (totaling 419) within the communities as specific research units.

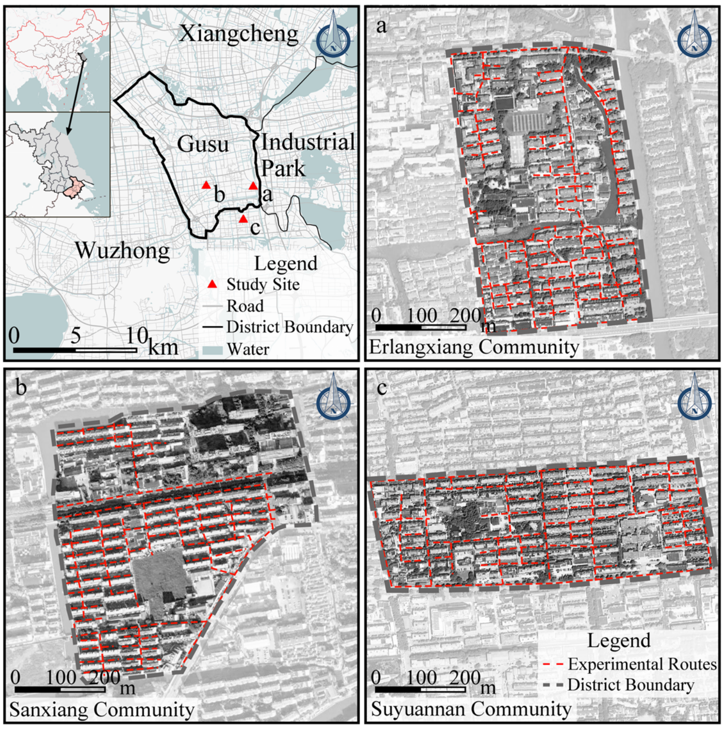

Figure 1. Study areas in Suzhou: (**a**) Erlangxiang Community; (**b**) Sanxiang Community; (**c**) Suyuannan Community.

In accordance with the Law of the People's Republic of China on Protection of the Rights and Interests of the Elderly [32], individuals aged 50–59, known as "the young old", were included in the study, and older adults in the community were defined as residents aged 50 and over. Furthermore, this study was targeted toward older adults who had lived in their communities for more than one year, and was carried out between 22–30 October 2022.

2.2. Measure of Physical Environmental Factors

Building on previous research, we evaluated the physical and social activities of older adults at the community scale using three key dimensions: walking conditions, infrastructure provisions, and natural environmental quality [21,22,33]. As mentioned in previous research [21,22], 11 physical environmental factors were compiled from the three aspects of walking conditions, infrastructure provisions, and natural environmental quality (Table 1). Drawing upon knowledge of community street space planning and design, these factors were considered to potentially influence the walking and social interactions of older adults [7,33–36]. In particular, street cleanliness (SCN) and green visibility (GSVN), were selected due to their importance in shaping not only the aesthetic appeal of street environments but also the physical and mental comfort of older adults. Clean streets provide safer, more appealing environments, while green visibility reduces stress and fosters social engagement [7,37]. Table 1 offers a detailed overview of the physical environmental factors, data collection, and measures. We utilized a combination of online open-source data, field survey data, and expert ratings to quantify the physical environmental factors.

Table 1. The selection, collection, and quantification of physical environmental factors.

Physical Environmental Factors	Layer 1	Layer 2	Collection and Measures
Walking conditions	Spatial scale	Relationship between pedestrians and vehicles (W_N) [1]	The relationship between pedestrian and motor vehicle traffic spaces in community streets is characterized as follows: 0 represents pedestrian-vehicle mixed-use; 1 represents separation of pedestrian and vehicle spaces
		Relative width of walkways (W_{ij})	Using open-source map data, W_{ij} was computed according to the following formula: $Wij = W_i / W_j$, (1) where W_i represents the width of walkways, and W_j represents the total width of a street. A higher ratio indicates a greater expanse for walking within the community streets [7].
	Accessibility	Network quantity penalized by distance ($NQPD_j$)	$NQPD_j$ is a form of closeness, commonly referred to as a gravity model, that takes into account both the quantity and the accessibility of the network weight. $NQPD_j$ was calculated according to the following formula: $NQPD_j = \sum_j(WP_jPP_j)/dm(j,n), (j = 1, 2, 3, \ldots, n)$, (2) where the set of polylines in the global spatial system is denoted as j, WP_j represents the weight of a polyline j within a unit, PP_j represents the proportion of any polyline n within the radius, and $dm(j,n)$ denotes an origin polyline j and a destination polyline n [38]. This term measures the accessibility of a network within a search radius. According to Cooper [38], $NQPD_j$ was calculated by sDNA.
		Betweenness/800 m (AB_N) [2]	This term measures the probability of traffic flow passing through the road network within the search radius. According to Cooper [38], AB_N was calculated by sDNA.
Infrastructure provisions	Diversity of functions	Mixed degree of functions (P_{Ni}) [3]	Using point-of-interest (POI) data obtained from OpenStreetMap [35] and field research, P_{Ni} was quantified by the following formula: $P_{Ni} = -\sum^{n}_{i=1}(P_i \times \ln P_i), (i = 1, 2, 3, \ldots, n)$, (3) where $\ln P_i$ represents the total number of POIs within a unit, P_i represents the ratio of the total number of a specific type of POI to $\ln P_i$, and n represents the total number of POI categories in the street unit [39].
		Density of functions (P_N)	P_N was quantified by the following formula: $P_N = \ln P_i/L_j$, (4) where L_j represents the total length of a street unit.
	Convenience of facilities	Diversity of facilities (DF_N)	DF_N represents the number of potential pedestrian destinations for older adults (e.g., retail shops or recreational facilities) [33].
		Seat density (L_{ij})	L_{ij} was quantified by the following formula: $L_{ij} = L_i/L_j$, (5) where L_i represents the total length of seating within a street unit.
Natural environmental quality	Objective performance	Eye-level green visibility (GSV_N)	Urban street-level greenery was evaluated using Google Street View (GSV) images [36].
	Subjective perception	Street cleanliness (SC_N)	Expert inter-rate [4]
		Landscape evolution of green space (LE_N)	Expert inter-rate [4]

Notes. [1] Scale: 1—satisfied, 0.5—neutral, 0—very unsatisfied. Specifically, 1 indicates a strong positive impact; e.g., streets have a visually separated pedestrian lane and would definitely be chosen as a walking path, and 0 indicates a strong negative impact; e.g., streets have high motor vehicle volumes, and moderate- to high-speed motor vehicle traffic. [2] This is a term commonly used in spatial design network analysis (sDNA) to measure network accessibility. [3] According to the Spatial Planning Guidance: Community Life Unit (MNR, 2021), public service functions were classified into six categories; namely, commercial, educational, medical, cultural, sports, and elderly care, which were valued by POI data. [4] Fifteen experts were asked to indicate how car connections and street cleanliness influence older adults' choice of walking and social interactions in a particular street setting on a scale from −1.00 to 1.00 based on on-site photos.

2.3. Measure of the Walking and Social Interaction of Older Adults

Table 2 presents the types, characteristics, and contents of activities among older adults. Focus was specifically placed on two types of activities: walking and social interaction. Three student groups examined the activities of older adults across 419 research units (walkable streets) within the three communities during three peak activity periods on sunny days: 10:00–10:30, 14:00–14:30, and 16:00–16:30. Utilizing photography, each group recorded the activity levels of older adults engaged in various activities, while also noting the ages of participants and their length of residence within the community.

Table 2. The activity type, characteristics, and contents of older adults.

Activity Type	Activity Characteristics	Activity Contents
Walking	Transient activities	Walking, brisk walking, running, etc. [40]
Social interaction	Transient and stationary activities	Accompanied by socializing, playing cards, entertainment, etc., or accompanied by walking with a conversation [25,41]

2.4. Data Analysis

We employed the multiple linear regression (MLR) model to describe and explain how the physical environmental factors of community streets influence the characteristics of walking behavior and social interaction. SPSS software (version 25.0 for Windows; SPSS, Chicago, IL, USA) was used for descriptive statistics and correlation analysis.

Stepwise regression was used to exclude the insignificant independent variables, resulting in Model 1:

$$F_N = \beta_0 + \beta_1 W_N + \beta_2 Wij + \beta_3 NQPD_j + \beta_4 AB_N + \beta_5 P_{Ni} + \beta_6 P_N + \beta_7 DF_N + \beta_8 L_{ij} + \beta_9 GSV_N + \beta_{10} SC_N + \beta_{11} LE_N \quad (6)$$

where F_N denotes the activity volume of older adults. Our analysis of Model 1, which relies on single-variable regression, reveals that indicators such as Infrastructure Provisions and Natural Environmental Quality were not included in the model's results, and the overall fit lacked statistical significance. It is crucial to consider the importance of facility usage efficiency under varying environmental qualities [42], as well as the differences in the spatial locations of functional facilities [43]. Moreover, the commuting from multipurpose non-work trips of older adults must be acknowledged [44,45]. Therefore, following the methodology proposed by Xia et al. [46], the following two sets of interaction variables were considered.

- Functional environmental interaction variables: Eye-level green visibility (GSV_N) was utilized to adjust the diversity of facilities (DF_N), resulting in the formation of an interaction variable X_1. This variable portrays the varying allure of street spaces with different facility diversities under eye-level green visibility. It illustrates the combined impact of facility diversity and environmental quality on outdoor health activities for older adults.
- Functional and accessibility interaction variables: Betweenness (AB_N) was used to adjust the mixed degree of functions (P_{Ni}), forming an interaction variable X_2. This variable highlights the attractiveness of street spaces with different functional diversities in streets accessible by walking, illustrating the combined effects of functional diversity and spatial characteristics on outdoor activities among older adults.

Taking these interaction variables into account, Model 2 was established.

$$F_N = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 \quad (7)$$

Composite variables effectively integrate the effects of functional facilities and other pertinent factors. The results from the multiple regression models, both before and after the introduction of interaction variables, are presented. Additionally, we analyze the disparities in the relationship between the physical environmental factors of community streets and the walking behavior and social interaction behaviors of older adults.

3. Results and Analysis

3.1. General Statistics

3.1.1. Physical Environmental Factors

Table 3 reports the descriptive statistics of the 11 physical environmental factors across the 419 walkways. The standard deviation of walking conditions was found to be far smaller than the mean, indicating an uneven distribution of those factors. Additionally, the infrastructure provisions showed a much larger standard deviation compared to the mean, highlighting the inconsistent availability of community infrastructure among the 419 units. Moreover, the low mean values for the mixed degree of functions (P_{Ni}), density of functions (P_N), and seat density (L_{ij}) − P_{Ni} (0.051) > P_N (0.012) > L_{ij} (0.007)—highlight the limited infrastructure in available in older communities. Specifically, the diversity of facilities (DF_N) had the highest mean among all the factors of infrastructure provisions, which represents a good number of potential pedestrian destinations for older adults (e.g., retail shops or recreational facilities) [33]. The large standard deviations indicated that older urban communities lacked uniformity in infrastructure, potentially leading to differences in walking behaviors and social opportunities for older adults. In addition, in comparison to street cleanliness (*SC*), the landscape evolution of green spaces (*LE*) demonstrated substantially more significant disparities between most of its data values and the mean. This indicated that the difference in landscape evolution (LE_N) within the study units was more significant. It is noteworthy that the variations in eye-level green visibility (GSV_N) within the study units are not substantial but consistently low, which is related to the generally low overall greening levels across the three old urban communities.

Table 3. The statistical results of physical environmental factors in the study area [1].

Physical Environmental Factors	Variables	Mean	Std.	Min	Max
Walking conditions	Relationship between pedestrians and vehicles (W_N) [2]	0.560	0.162	0.000	1.000
	Relative width of walkways (W_{ij})	0.416	0.395	0.100	1.000
	Network quantity penalized by distance ($NQPD_j$)	2.892	0.818	1.718	5.129
	Betweenness/800 m (AB_N)	73,601.680	92,233.720	1312.330	113,160.000
Infrastructure provisions	Mixed degree of functions (P_{Ni})	0.051	0.180	0.000	1.099
	Density of functions (P_N)	0.012	0.029	0.000	0.191
	Diversity of facilities (DF_N)	0.150	0.485	0.000	3.000
	Seat density (L_{ij})	0.007	0.035	0.000	0.355
Natural environmental quality	Eye-level green visibility (GSV_N)	0.212	0.118	0.016	0.560
	Street cleanliness (SC_N) [2]	−0.030	0.635	−1.000	1.000
	Landscape evolution of green space (LE_N) [3]	−0.350	0.555	−1.000	1.000

Notes. [1] All data in the multiple linear regression model were standardized. [2] Scale: 1—satisfied, 0.5—neutral, 0—very unsatisfied. [3] scale: 1—satisfied, 0.5—slightly satisfied, 0—neutral, −0.5—slightly unsatisfied, −1—very unsatisfied.

To further analyze the physical environment in old urban communities, a correlation analysis was conducted on the variables for the aforementioned indicators. Table 4 shows significant correlations among walking conditions variables such as the relationship between pedestrians and vehicles, the relative width of walkways, network quantity penalized by distance, and betweenness/800 m ($|r| = 0.676–0.957$, $p < 0.01$). These findings suggest that street spaces with high pedestrian accessibility within communities often adopt a traffic organization model characterized by the separation of pedestrian and vehicle spaces, and the relative width of pedestrian pathways tends to be relatively narrow. The indicators for the functional dimension exhibit only weak correlations with variables such as the relationship between pedestrians and vehicles, the relative width of pedestrian pathways, network quantity penalized by distance, and diversity of facilities ($|r| = 0.208–0.282$, $p < 0.01$), indicating that the diversity of living service functions in these communities requires enhancement in terms of pedestrian accessibility and the quality of the spatial environment. The natural environmental quality dimension indicators show a weak correlation with network quantity penalized by distance, betweenness/800 m, mixed degree of functions, and diversity of facilities (|r| = 0.215–0.358, $p < 0.01$). This finding implies that while there is no significant differentiation in the spatial environmental quality of various street spaces within the community due to street location or differences in spatial use, there remains a certain degree of association with indicators such as street accessibility and infrastructure provisions.

Table 4. Correlation analysis of the variables for the indicators.

	W_N	W_{ij}	$NQPD_j$	AB_N	P_{Ni}	P_N	DF_N	L_{ij}	GSV_N	SC_N	LE_N
W_N	1										
W_{ij}	−0.957 **	1									
$NQPD_j$	0.702 **	−0.676 **	1								
AB_N	0.897 **	−0.884 **	0.801 **	1							
P_{Ni}	−0.011	0.028	0.112	0.034	1						
P_N	0.282 **	−0.208 *	0.276 **	0.180	0.552 **	1					
DF_N	−0.139	0.153	−0.175	−0.131	0.251 **	0.215 *	1				
L_{ij}	0.038	−0.014	0.086	0.101	0.239 *	0.140	0.268 **	1			
GSV_N	0.061	−0.094	−0.165	0.024	0.073	0.013	0.174	0.024	1		
SC_N	0.037	−0.058	0.291 **	0.215 *	0.228 *	0.049	0.143	0.152	0.078	1	
LE_N	0.080	−0.084	−0.220 *	−0.042	0.054	0.125	0.358 **	−0.034	0.446 **	−0.013	1

Notes. * $p < 0.05$, ** $p < 0.01$; W_N—relationship between pedestrians and vehicles; W_{ij}—relative width of walkways; $NQPD_j$—network quantity penalized by distance; AB_N—betweenness/800 m; mixed degree P_{Ni}—mixed degree of functions; P_N—density of functions; DF_N—diversity of facilities; L_{ij}—seat density; GSV_N—eye-level green visibility; SC_N—street cleanliness; LE_N—landscape evolution of green space.

3.1.2. Activities of Older Adults

After accounting for differences in community population sizes, the statistical results of older adults' activity flows were standardized. Using the Erlangxiang community as a reference, the standardized coefficients for the Suyuan and Sanxiang communities were 1.1 and 0.7, respectively. Table 5 displays the statistical results of the activity flows of older adults across the 419 units.

Table 5. The statistical results of activity flows for older adults in the study area.

Activity Type	Numbers	Mean	Std.	Median	Min	Max
Walking	419	4.617	9.388	2	0	100
Social interaction	419	2.317	6.862	0	0	60
Sum	419	7.402	14.569	3	0	147

First, the statistical results indicated a noteworthy dispersion of activity flows across different street units, with the standard deviation of the total activity of older adults surpassing the mean. Specifically, the variability in walking behavior exceeded that of social interaction activities, highlighting pronounced differences in walking activities among elderly individuals across the 419 study units. Second, the median values of all activity types were lower than the mean, indicating a positively skewed data distribution. This suggests that activities with high numbers of older adults are relatively rare. Additionally, the maximum amount of walking activity among older adults far surpasses that of social interaction, aligning with the common understanding that walking is one of the most prevalent daily activities for older individuals [40]. The results underscore the diverse activity patterns and flows among older adults across different units.

3.2. Regression Analysis

3.2.1. Comparison Between Model 1 and Model 2

The multiple linear regression (MLR) model was applied to estimate the parameters of the two models. Table 6 reports the regression results of Model 1 and Model 2, which reveal statistically significant correlations. The p-values of the F-test are all less than 0.005. After the basic model was extended by adding interaction terms, a higher goodness of fit was achieved; the adjusted R-square values for Model 1 and Model 2 are, respectively, 0.390 and 0.409.

Table 6. The regression results of the two models.

Total Volume of Activities for Older Adults (F_N)	Model 1	Model 2
(Intercept)	-	-
Relationship between pedestrians and vehicles (W_N)	-	-
Relative width of walkways (W_{ij})	-	-
Network quantity penalized by distance ($NQPD_j$)	-	-
Betweenness/800 m (AB_N)	0.445 (0.000) ***	0.443 (0.000) ***
Mixed degree of functions (P_{Ni})	0.173 (0.000) ***	0.186 (0.000) ***
Density of functions (P_N)	-	-
Diversity of facilities (DF_N)	0.280 (0.000) ***	-
Seat density (L_{ij})	-	-
Eye-level green visibility (GSV_N)	-	-
Street cleanliness (SC_N)	-	-
Landscape evolution of green space (LE_N)	-	-
GSV_N*DF_N (X_1)	-	0.310 (0.00) ***
AB_N*P_{Ni} (X_2)	-	-
N	419	419
Multiple R-squared	0.394	0.413
Adjusted R-squared	0.390	0.409
F-statistic p-value	0.000	0.000

Notes. Coefficients and standard errors. *** $p < 0.001$. Dependent variable: total volume of activities for older adults.

The first column in Table 6 exhibits the multiple regression results of Model 1. Betweenness (AB_N), the mixed degree of functions (P_{Ni}), and the diversity of facilities (DF_N) were found to have positively significant effects on the total volume of activities for older adults, i.e., AB_N (0.445) > DF_N (0.280) > P_{Ni} (0.173). As reported in Section 3.1.1, these significant physical environmental factors have higher mean values. The findings are in agreement with arguments made in previous studies of the activities of older adults [6,19]. These studies held that the walkability and infrastructure provisions should increase with the active living behaviors of older adults [7,15,47]. However, it is important to note that, according to Model 1, there was no significant relationship between eye-level green visibility (GSV_N) and the active living behaviors of older adults, which differs from the findings of previous studies [37].

From Model 1, it became clear that the regression analysis model using single variables does not provide a significant fit for the Total Volume of Activities for Older Adults. Furthermore, indicators related to dimensions such as Infrastructure Provisions and Natural Environmental Quality were not included in the model. Therefore, a combined variables approach was adopted to better capture the synergistic effects of different physical environmental factors on older adults' activities [46]. This study proposes combining indicators such as AB_N, DF_N, GSV_N, and P_{Ni} to derive two effective combined variables: the Functional environmental interaction variables (GSV_N*DF_N) and the Functional and accessibility interaction variables (AB_N*P_{Ni}). GSV_N*DF_N represents the synergistic impact of diverse facilities and the quality of the spatial environment on the Activities for Older Adults. Meanwhile, AB_N*P_{Ni} reflects the combined effect of spatial accessibility and functional attractiveness on the Activities for Older Adults.

Different reference groups of physical environment factors were chosen for interaction analysis, and the impacts of these factors on the total amount of active living behaviors and different types of activities among older adults were verified by Model 2; AB_N (0.443) > GSV_N*DF_N (X_1) (0.310) > P_{Ni} (0.186). Accordingly, the probability of traffic flow passing through the road network was found to most strongly affect the active living behaviors of older adults. Among all the interaction terms, GSV_N*DF_N (X_1) and AB_N*P_{Ni} (X_2) had statistically significant relationships with the different activity types of older adults. It is worth noting that the coefficients and significance of betweenness (AB_N) and the mixed degree of functions (P_{Ni}) remained consistent with the results of Model 1. In particular, the effects of GSV_N*DF_N (X_1) are presented. The interaction of GSV_N with DF_N was found to have a significant positive influence on the total amount of active living behaviors of older adults. This is consistent with previous findings; namely, that covered walkways promote the active living of older adults for transport and social purposes [8]. Another trend is that seat density (L_{ij}) was found to have no significant impact on the activities of older adults, which contradicts previous research. One possible explanation for this is that lower seating levels result in the lower perceived availability of street furniture, such as sitting facilities for older adults [7].

3.2.2. Associations Between Physical Environmental Factors and Activities of Older Adults

Table 7 reports the estimated coefficients and F-statistic results for different reference activity types. The results reveal statistically significant relationships.

Table 7. The results of Model 2 with different types of reference activities of older adults.

Total Volume of Activities for Older Adults (F_N)	Walking as Reference Type (Model 2.1)	Social Interaction as Reference Type (Model 2.2)	Model Two
(Intercept)	-	-	-
Relationship between pedestrians and vehicles (W_N)	-	-	-
Relative width of walkways (W_{ij})	-	-	-
Network quantity penalized by distance ($NQPD_j$)	-	-	-
Betweenness (800 m) (AB_N)	0.224 (0.017) *	-	0.443 (0.000) ***
Mixed degree of functions (P_{Ni})	-	-	0.186 (0.000) ***
Density of functions (P_N)	0.225 (0.018) *	-	-
Diversity of facilities (DF_N)	-	-	-
Eye-level green visibility (GSV_N)	-	−0.180 (0.009) ***	-
Street cleanliness (SC_N)	-	-	-
Landscape evolution of green space (LE_N)	-	-	-
$GSV_N * DF_N$ (X_1)	0.190 (0.042) *	0.754 (0.000) ***	0.310 (0.00) ***
AB_N*P_{Ni} (X_2)	-	0.226 (0.001) **	-
N	419	419	419
Multiple R-squared	0.161	0.579	0.413
Adjusted R-squared	0.137	0.567	0.409
F-statistic p-value	0.000	0.000	0.000
(Intercept)	-	-	-

Notes. Coefficients and standard errors. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

First, the analysis shows a positive correlation between betweenness (AB_N) and both walking behavior and the overall activity levels of older adults, with coefficients of 0.224 and 0.443, respectively. Notably, among all factors related to walking conditions, betweenness stands out as the sole variable with a significant correlation, which is consistent with the findings of prior research examining the interplay between walking behavior and the built environment [20]. Furthermore, the results of the present study emphasize the profound impact of the probability of activity flow traversing the road network on older adults' engagement in active living, especially regarding walking behavior. This underscores the pivotal role of the built environment, particularly road networks, in shaping the activity patterns and behaviors of older adult populations. Understanding these correlations can inform urban planning and design interventions aimed at promoting active lifestyles and healthy aging among older adults. As such, optimizing the built environment, particularly the layout and connectivity of road networks, can foster environments conducive to physical activity and overall well-being for aging populations.

Second, the relationship between the mixed degree of functions (P_{Ni}) and the activity patterns of older adults provides intriguing insights. Notably, P_{Ni} demonstrates a significant positive impact solely on the total activity volume of older individuals, without exhibiting any notable correlation with the specific activity levels related to walking or social interaction. This suggests a complex interaction between urban infrastructure and overall activity engagement. One plausible explanation for this phenomenon is the diverse array of functional facilities encountered by older individuals during their walking routines. These facilities encompass a wide spectrum of services, including commercial establishments, educational institutions, medical facilities, cultural centers, sports venues, and elderly care facilities. It is conceivable that older adults may engage with these facilities while navigating their daily walking routes, thus contributing to their overall activity levels. Moreover, the introduction of interaction terms unveils an intriguing dynamic; namely, the synergistic effect between P_{Ni} and betweenness (AB_N) in facilitating social interaction among older adults. This phenomenon echoes previous research findings, which suggest that disparities in infrastructure elements such as intersections, pedestrian crossings, and traffic signals reflect variations in route preferences among older pedestrians [3]. Furthermore, variations in the distribution of functional facilities along these routes may influence the destination choices of older adults during their walks, potentially prompting them to pause and engage in social interactions within their community.

In summary, while the mixed degree of functions (P_{Ni}) primarily influences overall activity levels, its interaction with other factors, such as AB_N, plays a significant role in fostering social interaction. This underscores the intricate relationship between urban infrastructure, activity patterns, and social dynamics among older adults.

Third, the density of functions (P_N) demonstrates a significant positive association with the walking behavior of older adults, but lacks a significant correlation with their social interaction and overall activity levels. This suggests that higher functional density along streets encourages older adults to engage in walking. This phenomenon may indicate that older adults prefer to walk in areas with a rich array of functional facilities, while social interaction is influenced by a broader range of factors such as community culture and demographics. One possible reason for this is that there exists a more complex and indirect association between the density of functions and social interaction (Chen et al., 2024). Social interaction involves a wider range of interpersonal factors and community environmental influences, necessitating further analysis through combined variables to unravel this relationship.

Furthermore, among the natural environmental quality indicators, eye-level green visibility (GSV_N) was found to be the only factor significantly correlated with the activity level of older adults. Interestingly, GSV_N has a significant negative impact solely on the social interactions of older adults, while having no significant correlation with their walking behavior or overall activity level. This finding contrasts with previous research outcomes. This inconsistency may be attributed to the relatively low and homogeneous level of landscape greening in the old communities of Suzhou; the overall differences in eye-level green visibility (GSV_N) across the studied neighborhoods might not be substantial. Considering the potential synergies among environmental factors, several composite variables were introduced. Models incorporating GSV_N*DF_N (X_1) and AB_N*P_{Ni} (X_2) showed improved stability. Therefore, the results of the GSV_N composite variables were incorporated to further analyze the aforementioned factors.

The results indicate that GSV_N*DF_N (X_1) exhibits significant correlations with all three types of activities. In particular, it has a significant positive impact on the social interactions of older adults. Previous studies on the active mobility of older adults and the built environment might help explain this finding, as sheltered streets and facilities often provide more pleasant environments for both walking behavior and social interactions among older adults [20].

Our results also reveal the differential impacts of composite variables on social and walking activities. Compared to walking, the green visibility rate and diversity of facilities exert more significant influences on supporting the social interactions of older adults, with the former being the most influential among all factors affecting social interactions.

Understanding these dynamics is crucial for urban planners and policymakers aiming to create age-friendly environments that foster the well-being and social inclusion of aging populations. By recognizing the nuanced relationships between environmental factors and the activities of older adults, tailored interventions can be developed to improve quality of life, encouraging both physical activity and social interaction within communities. Moreover, the results underscore the importance of incorporating specific environmental features, such as eye-level green visibility, into urban planning and design strategies for older adult populations. Enhancing the visibility of greenery at eye level within neighborhoods can potentially foster greater social interactions among older adults, contributing to a sense of community and belonging.

4. Discussion

In the public spaces of aging communities, walking conditions, functional facilities, and environmental quality collectively play a vital role in shaping the outdoor health activities of older adults [48,49]. This study analyzed the relationship between these factors and the activity patterns of older adults, focusing on both walking behaviors and social interactions. Our findings reveal that models based solely on spatial or functional features are insufficient in explaining the complex patterns and distribution characteristics of activities among the elderly. Additionally, the additive effects of environmental features, such as green visibility and infrastructure, cannot be fully measured without considering their synergistic interactions. This highlights the importance of incorporating the complementarity and interplay of various factors to improve model accuracy and interpretability.

We employed a comprehensive regression analysis model, utilizing the composite variable functional environmental coefficient (X_1) and functional spatial coefficient (X_2), which together can explain 13.7% of the total walking activities, 56.7% of the social interaction activities, and 40.9% of the total activities of older adults. These findings suggest that the interaction of environmental factors, rather than their isolated effects, is critical for understanding how older adults engage with their surroundings. The results align with the argument by Besser et al. [4] that cognition and physical activities in older adults are closely tied to the neighborhood environment, reinforcing the need to design supportive urban spaces.

4.1. Synergy Between Physical Environmental Factors and Older Adults' Activities in Aging Communities

The functional environmental interaction variable (GSV_N*DF_N, X_1) refers to the attractiveness of diverse facilities in community public spaces under different spatial greenery and landscape quality conditions. It significantly influences the total outdoor health activities and social interaction activities of older adults. The synergy between facility diversity and green visibility encourages leisure activities such as lingering and conversation, leading to crowd gathering and subsequent social interactions. Community spaces with a variety of activity facilities and lush shade trees or pavilions attract significant foot traffic and stimulate various activities. Conversely, spaces lacking greenery or shading alongside activity facilities have diminished attractiveness to older adults, necessitating a comprehensive consideration of both factors.

The functional and accessibility interaction variable (AB_N*P_{Ni}, X_2) denotes the spatial attractiveness of mixed functions in streets with different degrees of integration in community public spaces. It significantly impacts social interaction activities among older adults and also influences their total outdoor health activities. The synergy between functional diversity and integration facilitates walking as a mode of transportation for older adults, enhances the sustainability of original activities, and provides space and opportunities for more diverse activities. Streets with diverse commercial functions and convenient accessibility are more attractive to people. Conversely, streets with rich commercial functions but low walkability struggle to attract crowds or prolonged stays. Similarly, streets with high walkability but lacking functional diversity fail to stimulate outdoor health activities among older adults, failing to enhance the vitality of community public spaces.

This study shows that individual environmental factors alone may not fully explain the patterns of activity among older adults, but their combined effects create environments that better support active and social lifestyles in aging communities. Therefore, urban planners and designers should consider the synergistic effects of environmental factors, particularly in aging communities. Prioritizing the integration of greenery and diverse facilities, alongside ensuring that streets are walkable and accessible, will create public spaces that are not only physically but also socially supportive for older adults. This finding complements earlier studies by Nelson et al. [9], who argued that both physical activity and social interaction should be promoted simultaneously to improve public health outcomes for older populations.

4.2. Implications for Planning, Design, and Management

The results of this study emphasize the need for urban planning strategies that go beyond the traditional focus on infrastructure and incorporate a holistic view of the urban environment to promote active living among older adults. In agreement with Cerin et al. [7], our findings suggest that combining walkability, safety, and functional diversity is critical to creating environments that encourage both physical activity and social interaction. The role of walkable neighborhoods has been well-documented in studies such as those by Besser et al. [4] and Song et al. [8], which highlight that well-connected pedestrian networks improve accessibility and mobility for older adults. This study reaffirms these conclusions by showing that increased pedestrian–vehicle separation and enhanced pedestrian networks directly influence older adults' walking behavior and overall activity levels.

In line with previous research, this study supports the notion that walkability and physical infrastructure are critical factors in promoting active living among older adults. Similar to findings by O'Hern and Oxley [12], and Song and Kong [47], our study demonstrates that pedestrian–vehicle separation and connectivity of pedestrian networks can significantly influence the walking behaviors of older adults, reaffirming the importance of designing streets that prioritize pedestrian safety and accessibility. Improving pedestrian–vehicle separation and increasing network connectivity can reduce safety concerns and encourage more frequent and longer walking trips. Additionally, as described by Jiang et al. [23], designing streets with wider sidewalks, safer crossings, and designated pedestrian zones can encourage walking among older adults. This is especially important in older urban communities, where limited opportunities for renewal necessitate the optimization of existing street spaces for both safety and social interaction.

In addition, this study echoes the findings of Grasser et al. [33], who emphasize the importance of functional diversity in encouraging social interaction. Our results echo these conclusions, demonstrating that the availability and diversity of facilities, such as retail shops, recreational areas, and healthcare centers located within walkable distances, are crucial for encouraging social engagement among older adults. Enhancing the diversity of street-level facilities can attract older adults to public spaces, thus promoting opportunities for social interaction [47,50]. Mixed-use streets with a range of functions are more likely to encourage walking trips and social activities among older adults. Communities should be designed with accessible amenities, strategically located along walking routes to maximize their use by older adults, similar to what Grasser et al. [33] described in urban studies.

Natural elements, such as greenery, also play a crucial role in improving urban environments for older adults. Our findings on eye-level green visibility align with those of De Keijzer et al. [37] and Liu et al. [36], which underscore the psychological benefits of greenery in reducing stress and enhancing well-being. Incorporating green buffers, tree planting, and landscaping along pedestrian pathways not only improves the visual appeal of the environment but also fosters a sense of community and social inclusion. Increasing shaded vegetation and optimizing the layout of rest areas can significantly encourage older adults to engage in outdoor activities and social interactions [51]. For instance, strategically placed benches under trees or shaded pavilions can provide comfortable and attractive spots for rest, encourage social gatherings, and extended stays in public spaces.

These findings suggest that the integration of physical infrastructure, functional diversity, and natural environments can create age-friendly environments that promote active living and social engagement among older adults. Planners should focus on combining greenery, walkability, and functional integration to create spaces that cater to mobility needs while also fostering community-building and social inclusion.

Moreover, this research highlights the importance of considering the synergistic effects of environmental factors rather than treating them in isolation. By designing spaces that enhance both physical activity and social interaction, cities can become more inclusive and supportive of their aging populations.

5. Conclusions

This study provides a comprehensive analysis of how physical environmental factors influence the walking behavior and social interaction of older adults in three old urban communities in Suzhou. By examining walking conditions, infrastructure provisions, and natural environmental quality, the research highlights how these factors interact to shape the activity patterns of older adults. The findings reveal the importance of considering the synergy between green visibility, facility diversity, and spatial integration when promoting healthy aging through outdoor physical activities and social engagement.

The research introduces two composite variables: functional environmental interaction and functional and accessibility interaction, both of which have a significant impact on the activities of older adults. These findings suggest that integrating diverse urban functions with high walkability and aesthetically pleasing green spaces is crucial for creating engaging, age-friendly environments. This aligns with previous studies, such as those by Grasser et al. [33] and Cerin et al. [7], which emphasize the role of built environment features in fostering active and social lifestyles among older populations.

The results carry practical implications for urban planners and policymakers. Designing environments that encourage both mobility and social interaction by improving infrastructure, enhancing green visibility, and ensuring functional diversity is critical to creating inclusive urban spaces that cater to the needs of older adults. This is consistent with the WHO's guidelines for age-friendly cities [5], reinforcing the idea that urban environments must support active aging through holistic design approaches.

However, the study has limitations. First, it focuses only on three communities and does not include cross-community or cross-age comparisons, which may limit the generalizability of the findings. Second, the relatively low R-squared values suggest that additional factors may need to be explored in future research, to better understand the environmental impacts on older adults' activities. Expanding the dataset and refining model structures will provide a more robust understanding of the role of community environments in promoting healthy aging.

In summary, this study emphasizes the importance of synergistic environmental factors in encouraging active and socially engaged lifestyles among older adults. It provides valuable insights for future urban planning and policy initiatives aimed at supporting healthy aging in old urban communities; reinforcing the need for integrated approaches that combine physical, functional, and natural elements to enhance the quality of life for aging populations.

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