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Understanding the long-term effects of public open space on older adults' functional ability and mental health

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ABSTRACT

Little is known about how public open space (POS) environment quality and vitality influence older adults' functional ability and mental health over time. POS vitality refers to the capacity of POS to accommodate a variety of users and activities. We undertook a four-year longitudinal survey of 2081 older adults in Hong Kong to investigate longitudinal relationships between POS environment quality, POS vitality, functional ability and mental health. We applied environment quality evaluation and space use behavior observation to collect data on the environment quality and vitality of POSs within the 200-m buffer area of participants' residences. POS environment quality attributes included the number of leisure facility types, accessibility, shade, and bench quality. POS vitality attributes comprised the diversity of users and activities. We used the Chinese Lawton Instrumental Activities of Daily Living Scale to measure older adults' functional ability and the Geriatric Depression Scale (15-item) to evaluate mental health. We applied latent growth curve models to analyze the longitudinal associations. Accessibility to POS and social interactions among users in POS were related to better functional ability and mental health among older adults at baseline. The number of leisure facility types, and social interactions among users in POS led to a slower decline in functional ability over time. However, there were no significant associations between POS and mental health over time. These findings have theoretical implications for the healthy aging research framework and practical insights for planning policies using POS as an intervention tool to facilitate older adults' healthy aging.

1. Introduction

Public open space (POS) is a significant component of liveable neighborhoods. POS refers to space designed for recreation to which the public has unimpeded access, such as parks, pitches, and game courts [1–3]. There has been a long history for urban planners and urban designers using POS as an intervention tool to improve the health and wellbeing across life course [3–5]. In general, POS benefits include encouraging physical activities, facilitating social interaction [1], reducing chronic diseases (e.g., obesity, cardiovascular disease) [6,7], and mitigating health consequences caused by climate change [8].

POS is an essential element of age-friendly neighborhoods. A good-quality POS can enable older adults to maintain good functional ability and mental health by facilitating capacity-enhancing behaviors (i.e., physical activities, social activities) within nearby neighborhoods [1]. Maintaining good functional ability and mental health among older adults is the imperative of aging policies. Indeed, the World Health Organization (WHO) announced 2020–2030 as the Decade of Healthy

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Aging, and highlights the importance of environments in maintaining health and independence of older adults [9]. Therefore, providing good-quality POS is essential in building age-friendly neighborhoods and implementing healthy aging policies.

Despite its importance, insufficient attention has been paid to the POS health benefits among older adults. Limited studies found that POS encourages walking and social interactions among older adults [10–13]. Sugiyama and his colleagues suggested that POS environment quality and safety were positively related to the quality of life among older adults in Britain [13]. Nevertheless, existing studies are limited by three aspects. First, few studies have directly linked POS characteristics to health outcomes of older adults, such as functional ability and mental health. Second, few scholars have investigated impacts from POS vitality (i.e., the capacity of accommodating various activities and users) on older adults' health outcomes. Third, existing studies only use cross-sectional data to prove the POS benefits, thereby failing to reduce the impact of residential self-selection bias [14,15]. Residential self-selection refers to older adults' tendency to select their neighborhoods based on their personal preferences and lifestyle. Therefore, those who are active and healthy or who want to be active and healthy may choose to live in a neighborhood that is well-endowed with POS. Accordingly, better functional ability and mental health of older adults in neighborhoods with adequate POS may not directly result from POS environment quality and vitality in these neighborhoods. These cross-sectional studies have been unable to identify a causal relationship between POS environment, functional ability, and mental health among older adults. Therefore, existing knowledge on POS and older adults' health is limited, restricting the effectiveness of using POS as a built environment intervention in promoting healthy aging.

To fill these gaps, this study investigated longitudinal relationships between POS environment quality, POS vitality, functional ability and mental health of older adults, using POS data collected by the method of environment quality evaluation and space use behavior observation and longitudinal survey data in 12 public rental housing neighborhoods in Hong Kong. It addressed the research question: "To what extent are POS environment quality and POS vitality related to the initial status and changes in older adults' functional ability and mental health over time?" This study can reduce the impact from the problem of residential selection bias because it applies longitudinal data collected from the public rental housing neighborhoods in Hong Kong. The allocation of public housing units in Hong Kong is random and based on flat availability and family size [16], and thereby to a great extent diminishing the impact of self-selection bias on our research findings.

2. Literature review

2.1. Existing theories and frameworks

Existing theoretical research provides extensive discussion on the relationship between older adults' functional ability, mental health, and neighborhood environments [17–21]. Functional ability refers to older adults' ability to perform activities of daily living independently [22]. The Ecological Model of Aging argues that older adults' functional ability and mental health are determined by individual competences (e.g., cognitive function) and the influence of neighborhood environments [18]. The interplay between individual and neighborhood environments changes over time. However, Glass and Balfour contend that the model has underestimated the facilitating role of neighborhood environments [19]. Facilities in neighborhoods such as POS support older adults' capacity-enhancing activities, which contribute to better functional ability and mental health. Furthermore, Wahl and his colleagues introduce the life course perspective into the Ecological Model of Aging and emphasize the cumulative impact of the interplay process over time [20].

The Healthy Aging Research Framework also lays a theoretical ground for exploring the relationship between POS, functional ability, and mental health among older adults over time [9,21]. As a significant element within supportive neighborhoods, POS can facilitate the process of enhancing and maintaining older adults' functional ability and mental health. Based on the Healthy Aging Research Framework, older adults' functional ability and mental health are influenced by individual intrinsic capacity, POS environment characteristics, and the interactions between them. Despite low intrinsic capacities, older adults can continue to do what they have reasons to value, such as social interactions and physical activities, when they have access to a good-quality POS. In this case, their functional ability and mental health can be largely maintained. Additionally, the interactions between intrinsic capacities and POS environments on functional ability and mental health could exert a cumulative impact across older adults' life course. Nevertheless, existing studies have not examined these theoretical relationships that are significant for further developing understanding of the impact of POS (i.e., an element of immediate residential environments) on older adults' health and facilitating healthy aging with environmental intervention worldwide.

2.2. Relationships between POS, functional abilities, and mental health

POS has been proven to facilitate physical and mental health among the general population in existing studies [1,3,23–25]. POS quantity attributes are positively associated with health benefits [1,25,26]. A close distance to, a larger number of, and more extensive total spatial area of POS are associated with more physical activities [1,26], better mental health [25], and local social interaction in neighborhoods [1] among the general population. POS quality attributes such as amenities and facilities are more significant in promoting health-related behaviors and mental health than its quantity attributes [3,24,27,28].

As a significant characteristic of POS, POS vitality has potential health benefits for older adults. POS vitality refers to the capacity of POS to accommodate a variety of users and activities [29–32]. POS vitality may yield health benefits for older adults for three reasons. First, diverse physical activities in POS attract older adults' participation in these activities and encourage the development of an active lifestyle. Second, a POS with a high level of vitality presents a lively scene and attracts older adults to socialize with others in a shared environment [33–35]. As a shared place for all generations, POS can facilitate social interactions and social support between different generations in local neighborhoods [36], reducing the prevalence and adverse impacts of social isolation for older adults. By participating in social activities in POS [37], older adults can foster a sense of connectedness and fulfilment [4]. Third, individuals may experience positive emotions, even without direct use, by simply viewing the nature and lively scenes in POS [3]. However, few studies have examined the long-term health benefits of POS vitality on older adults' functional ability and mental health with large-scale environment quality evaluation and space use behavior observation data.

2.3. Methods on evaluating environment quality and vitality of POS

Scholars have developed several audit tools to measure the environment quality of POS, such as Environment Assessment of Public Recreation Spaces (EAPRS) [38], Community Park Audit Tool (CPAT) [39], Physical Activity Resources Assessment Instrument (PARA) [40], and Public Open Space Tool (POST) [41]. However, these POS audit tools have been criticised for two reasons. First, these audit tools mainly focus on built environment attributes which facilitate physical activities among younger generations [42]. Second, some items from the audit tools are irrelevant to the context of urban POS in Asian societies, such as the presence of barbecues and the presence of a rugby field [28]. Besides, these audit tools ignore the fact that ability to access POS and the purpose of POS use vary across different age groups. Specifically, it becomes increasingly difficult for older adults to access POS with low accessibility (e.g., high terrain slope, many steps) as their functional

abilities decline gradually [43]. Comparing with young people, older adults tend to use benches with shading more often to socialize with others [44]. Therefore, it is necessary to develop an older-adult-oriented POS environment quality measurement.

Regarding the measurement of POS vitality, Goličnik and Thompson applied behavior mapping and GIS techniques to capture users' behaviors in Edinburgh and Ljubljana [45]. They recorded the activity location, content, and users' attributes on site. Despite revealing comprehensive information, these methods are difficult to apply to large-scale POS users' behavior observations due to high data collection cost and being time consuming. Mehta measured the diversity of users and activity types by on-site observation with a four-point Likert scale in seven public spaces in Tampa [37]. Nevertheless, this method only unravels the relative assessment of user diversity and activity types between selected POSs, but fails to reflect the actual situation. This measurement method may lead to an overestimation in the impacts of POS vitality. Thus, measurements unravelling the actual situation of user diversity and activity types are significant in estimating the impacts of POS vitality.

3. Material and methods

We used individual-level data and neighborhood-level public open space (POS) data to conduct the analysis. The individual-level data were derived from a longitudinal questionnaire survey in Hong Kong. The neighborhood-level public open space data were collected by the method of environment quality evaluation and space use behavior observation. First, we evaluated the environment quality and observed users' behaviors in each selected POS. Second, we calculated seven indicators representing the environment quality and vitality of each POS. Third, we measured the area of each POS and used it as the weight to calculate the area-weighted mean of the above-mentioned indicators. Fourth, we aggregated the score of a POS indicator to the level of the 200-m buffer area of each sample neighborhood by calculating the area-weighted mean of each indicator. The area-weighted mean indicates the importance of POS area in revealing POS environment quality and vitality at the 200-m buffer area (i.e.,neighborhood-level). We used Fig. 1 to simplified this process.

3.1. Data collection

3.1.1. Individual-level data

We conducted a longitudinal questionnaire survey of older adults in public rental housing estates in Hong Kong between 2014 and 2017. As a typical Asian city, Hong Kong is distinguished by cramped living space, large population density, and compact development [46]. Most older adults have convenient access to local POS and other facilities. Around 55.9% of the older adult population live in government-subsidized housing estates, most of whom have resided in these estates for more than 30 years [47,48]. Studies of public rental housing estates can reveal the cumulative impacts of POS on older adults more clearly. Public rental housing in Hong Kong is only randomly assigned to low-income household and subject to flat availability and family size [16]. These residents have fewer financial resources to move and thereby reside in the same neighborhood for a longer time compared with others. They are more bound to the local neighborhoods and have more daily interactions with the neighborhood environments. Therefore, longitudinal studies in public rental housing estates can reveal the cumulative impacts of POS more clearly. Besides, studies of public rental housing can reduce the effect of self-selection. Living in these estates for three decades, older adults moved to these estates before they became physically frail or mentally ill. In this case, this study advances our knowledge of the cumulative effects of POS on functional ability and mental health among older adults over time.

Participants were eligible if they were 65 years old and above, without known dementia or other psychiatric disorder, and able to speak Cantonese. The survey applied the stratified random sampling method based on age groups to choose participants from the 12 sampled public rental housing neighborhoods (Fig. 2). Specifically, participants were randomly selected in the ratio of 50:60:70 among the three age groups, including young-old (65–74 years), middle-old (75–84 years), and oldest-old (85 years and older).[1] We chose this sampling rate mainly because there was a higher attrition rate among the middle-old and oldest-old age groups in existing longitudinal studies [49]. We recruited 2081 participants at baseline. The questionnaire covered sociodemographic characteristics, functional ability, and mental health. This study was approved by the Human Research Ethics Committee of The University of Hong Kong (Reference: EA050814 & EA1610004).

3.1.2. Neighborhood-level public open space data

The neighborhood-level public open space data were collected by the method of environment quality evaluation and space use behavior observation in the field. We collected data from POS within the 200-m network buffer area of each sample neighborhood. We selected the 200-m buffer area because this area accommodates most of the everyday activities of the participants [50]. Besides, this size of buffer area is proper to test the impacts from POS on older adults with different levels of functional abilities since it covers the POS within 10 min' walk from sample neighborhoods (for participants without walking difficulties). As a small size buffer radius, 200-m buffer radius can reveal the high-density nature of physical environments in local neighborhoods in Hong Kong, which has been applied in previous studies [51].

Environment quality evaluation captured the environment quality of POS within the 200-m network buffer area of sample neighborhoods. We included 145 POS that met two criteria: 1) designed for active or passive recreation; 2) open to the public. Trained assessors applied the Public Open Space Tool (adapted version) to evaluate environment quality [41], including the number of leisure facility types, accessibility, shade, and bench quality. We used Google Earth Engine to calculate the total area of each POS. We conducted a pilot study to identify a widely used walking route from the central point of sample neighborhood to each POS based on on-site interviews with the residents. Then, trained assessors evaluated the assessbility to POS for wheelchair-bound older adults based on the identified walking route. Finally, trained assessors evaluated the remaining aspects of POS environment quality.

Space use behavior observation collected data regarding POS vitality. We conducted data collection on non-rainy weekdays to generate typical space use behavior data. First, assessors conducted a pilot study in each POS to identify a walking route for space use behavior observation. Second, assessors spend two days to record the space use behaviors in the POS around one sampled neighborhood. Assessors walked through the POS on the designed walking route from the pilot study with a 360° video camera in five timeslots: early morning (6:00–9:00), late morning (9:00–12:00), early afternoon (12:00–15:00), late afternoon (15:00–18:00), and evening (18:00–20:00). There are 725 videos (145 × 5) in total. Third, assessors coded the space use behavior data based on the videos taken by the 360° video camera and a coding tool. The coding tool captured various attributes of users, including age group (i.e. children, youth, adult, older adult), gender, type of physical activities, the number of users conducting social interactions. Assessors coded the videos together and made cross-checks with each other until the inter-rater reliability reached 80%.

[1] Gerontologists have found that people experience different conditions when approaching old age. They divide older adults into three subgroups to reveal their diversity in physical and mental health. A commonly-used grouping is young-old (65–74 years), middle-old (75–84 years), and oldest-old (85 years and older) [66].

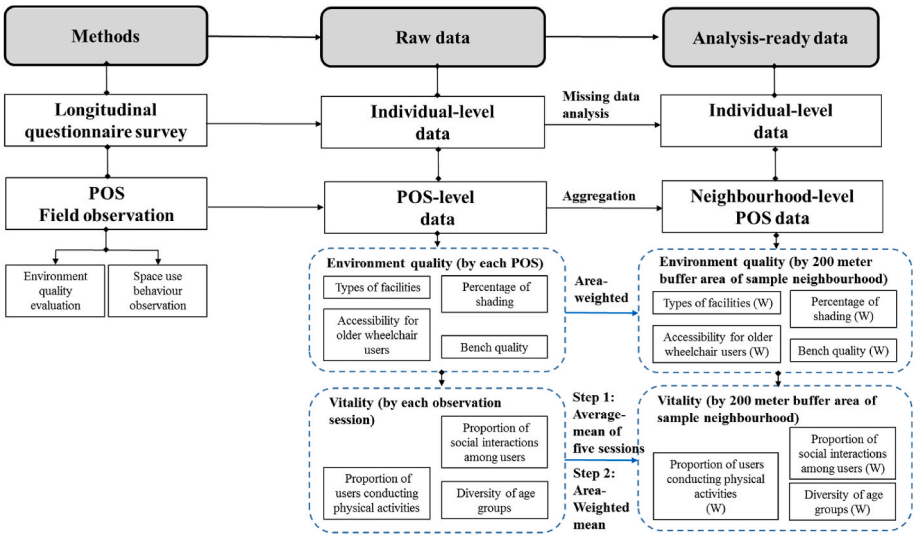

Fig. 1. Diagram illustrating the process of data collection and data preparation.

Fig. 2. The location of 12 sampled public rental housing neighborhoods.

3.2. Measurement

3.2.1. POS environment quality

Leisure facility refers to the facilities designed for conducting physical or leisure activities by users from different age groups in a POS, such as exercising amenities for older adults, chess areas, pebble walking trails, ping-pong tables, and children's playground. We measured it by the number of types.

Accessibility to POS refers to the potential for an older adult to reach a POS on foot [52]. We measured it by evaluating how easy it was for a wheelchair user older adult to access the entrance of a POS from the centroid point of the sampled neighborhood. We focused on four aspects: 1) distance from the centroid point of the neighborhood to the POS; 2) presence and features of stairs; 3) presence and features of slopes; 4) presence and effectiveness of barrier-free facilities (Supplementary Table 1). We used a three-point Likert scale to rate accessibility from 1 (difficult) to 3 (easy).

Shade refers to the percentage of shade in a POS.

Bench quality was evaluated on a three-point Likert-scale (1 = poor, 2 = fair, 3 = good).

The environment quality of sampled POS is shown in Supplementary Table 2. We aggregated the environment quality data of each POS to the level of the 200-m buffer area of each participant's home address by calculating the area-weighted mean of the above-mentioned indicators respectively within the 200-m buffer area (Table 2).

3.2.2. POS vitality

In line with Montgomery [30] and Jacobs [53], we measured POS vitality by the extent to which users and activities in POS were mixed. We calculated four indicators based on the data collected by space use behavior observation (Supplementary Table 3): the diversity of age groups, the diversity of activity types, the proportion of social interactions, and the proportion of users undertaking physical activities. Formulas calculating the four indicators by each POS each session are shown in Table 1. They ranged from 0 to 1, a higher score revealing a greater level of POS vitality (Table 2). The diversity of age groups and activity types was based on Simpson's index, which has been applied in urban planning, such as calculating diversity for landscape structure [54], land use [55], and housing type [56].

We aggregated the vitality data of each POS to the level of the 200-m buffer area of each participant's home address. First, we calculated the four vitality indicators by each POS each session (Tables 1 and 2). Second, we computed the average mean of the four indicators for each

Table 1
POS vitality indicators (by session).

Indicator	Formula	
Diversity of age	$1-\sum_{i=1}^{4}\left(\frac{n}{N}\right)^2$	N: total number of users in a session; n: the number of users in an age group (Children, Youth, Adults, Older adults); diversity of age ranges from 0–0.75, 0 no diversity, 0.75 diverse.
Diversity of activities	$1-\sum_{i=1}^{13}\left(\frac{n}{N}\right)^2$	N: total number of users in a session; n: the number of users in one type of physical activity group (conversing, caregiving, light-exercising, moderate-exercising, vigorous-exercising, eating, playing chess/poker, playing, reading, resting, smoking, using electronic device, others); diversity of activities ranges from 0–0.923, 0 no diversity, 0.923 diverse.
Proportion of social interactions	$\frac{N-single\ users}{N}$	N: total number of users in a session; single users: using POS alone;
Proportion of users conducting physical activities	$\frac{Users\ conducting\ physical\ activities}{N}$	N: total number of users in a session;

Table 2
Public open space vitality (by session).

	Min	Max	Mean	S.D.
Diversity of age groups	0.0	0.71	0.31	0.24
Diversity of activity types	0.0	0.83	0.37	0.28
Proportion of users conducting physical activities (percentage)	0.0	1.00	0.321	0.36
Proportion of social interactions among users (percentage)	0.0	1.00	0.416	0.36

Note: Sessions observing no users in the public open space (N = 226) were excluded in the calculation of diversity of age groups, diversity of activity types, and proportion of social interactions among users.

POS, respectively. Each POS had four indicators (average mean) to measure its vitality. Third, we calculated the area-weighted mean of the indicators respectively within the 200-m buffer area (Table 3).

3.2.3. Functional ability

We applied the Chinese Lawton Instrumental Activities of Daily Living scale (IADL) to measure functional ability. This scale was previously validated in Hong Kong [57]. The IADL scale consists of nine items essential for independent community living, covering the capabilities of using the telephone, shopping, transportation, food preparation, housekeeping, laundry, medication, and finances. Participants were invited to evaluate their ability on a three-point Likert scale, ranging from 0 ('Not capable of doing it') to 2 ('Fully capable of doing it without any help'). The total IADL score ranges from 0 to 18. A higher score suggests better independence. Cronbach's alpha was 0.894.

3.2.4. Mental health

We used the Geriatric Depression Scale 15-item version [58] to evaluate participants' mental health previously validated among Chinese participants [59]. Cronbach's alpha was 0.850. We requested participants to state the total number of specified symptoms they had experienced. The score ranges between 0 and 15, a higher score indicating more depressive symptoms.

Table 3
Baseline characteristics of participants and POS.

	Participants(N = 2081)	
	Mean/ Frequency	(S. D.)
IADL scores	14.88	4.61
GDS-15 scores	2.63	3.13
Age	79.64	7.97
Sex (Male): Ref	44.20	
Female	55.80	
Marital status (Single, divorced, widowed): Ref	40.80	
Married	59.20	
Educational attainment (Primary school and below): Ref	78.50	
Secondary school (junior and senior)	19.50	
Associate and above	2.00	
Number of chronic diseases at baseline (Two or more types of chronic disease) Ref	64.90	
One type of chronic disease	21.50	
No chronic disease	13.60	
Cognitive function (MoCA education adjusted score) at baseline	19.62	5.76
Self-rated health	3.27	0.86
Neighborhood socioeconomic status		
Median monthly family income (range = 1.30–2.13, unit: HK$ 10,000)	1.73	0.26
POS vitality		
Diversity of age groups (Weighted) (range = 0.08–0.54)	0.30	0.11
Proportion of social interactions among users (Weighted) (range = 0.14–0.65)	0.41	0.10
Proportion of users conducting physical activities (Weighted) (range = 0.05–0.75)	0.38	0.16
POS environment quality		
Types of facilities (Weighted) (range = 0.50–3.77)	1.66	0.76
Percentage of shading of POS (Weighted) (range = 0.08–0.68)	0.38	0.17
Accessibility for older wheelchair users (Weighted) (range = 1–3)	2.21	0.57
Bench quality of POS (Weighted) (range = 1.02–3.00)	2.50	0.55
Terrain slope (range = 0.26–25.68)	11.29	7.62

3.2.5. Individual-level and neighborhood-level covariates

We included neighborhood monthly family income (median) in the models to control for neighborhood-level confounding effects. We included age, sex, self-rated health, number of chronic diseases, education attainment, and marital status in the models as individual-level covariates.

3.3. Statistical analysis

We conducted latent growth curve modeling (hereafter LGCM) to examine longitudinal associations between POS environment quality, POS vitality, participants' functional ability, and mental health. First, we analyzed the missing data characteristics. Little's χ^2 test revealed that the attrition of IADL scores and GDS-15 scores, and missing covariates at baseline were covariate-dependent missing (χ^2 distance = 696.284, df = 812, $p = 0.998$; χ^2 distance = 41.518, df = 44, $p < 0.579$), which could be viewed as a case of missing at random [60]. Therefore, we decided to use full information maximum likelihood (hereafter FIML) to optimize statistical estimation and reduce bias [61]. FIML can model both missing covariates and outcome variables by calculating a likelihood function for each case grounded on the variables with available values. We then selected LGCM as the modeling method primarily because of its appropriateness for analyzing longitudinal survey data. Intraclass correlation coefficient (ICC) suggests that 0.9% and 1.2% variance of the two outcome variables (IADL and GDS-15 scores) over time were situated at the neighborhood level, indicating no significant evidence for clustering effects [62]. The advantages of LGCM are that it can model the initial status and changes of outcome variables over time. The estimated LGCM were as follows:

$$Y_{it} = \alpha_{iy} + \theta_{iy}\lambda_t + \sigma_1 L_{ab} + \varphi_1 E_{cb} + \omega_1 P_i + \varepsilon_{yit} \quad (1)$$

$$Z_{it} = \alpha_{iz} + \theta_{iz}\lambda_t + \sigma_2 L_{ab} + \varphi_2 E_{cb} + \omega_2 P_i + \varepsilon_{zit} \quad (2)$$

where Y_{it} and Z_{it} are the values of IADL and GDS-15 of participants i at time point t. α_{iy} and α_{iz} are the random intercepts for each participant. θ_{iy} and θ_{iz} denote the random slopes for each participant. λ_t is the parameter representing time. ε_{yit} and ε_{zit} are the errors for each participant at each time point. L_{ab} denotes the value of the POS vitality indicator a of building b. E_{cb} refers to the value of the POS environment quality indicator c of building b. P_i is a set of individual-level variables collected at baseline.

4. Results

4.1. Descriptive analysis

Table 3 summarizes participants' individual characteristics at baseline. Participants were 79.64 years old on average, and over half (55.8%) were female. Approximately 59.2% of participants were married. Most participants completed primary or below school education (78.5%). Over half had two or more types of chronic disease (64.9%). The average MoCA education-adjusted score was 19.62, and self-rated health was 3.27. For POS vitality, the average weighted score of the diversity of age groups was 0.30. The area-weighted averages of the proportion of social interactions among users and the proportion of users undertaking physical activities were 0.41 and 0.38, respectively. As for the POS environment quality, the average area-weighted score of the type of facilities was 1.66. The area-weighted mean of the percentage of shading of POS was 0.38, and accessibility for older wheelchair users

was 2.21. The area-weighted means of bench quality of POS and terrain slope were was 2.50 and 11.29, respectively.

4.2. Associations between POS environment, POS vitality, functional ability, and older adults' mental health over time

The results of two unconditional LGCM models show that participants had different initial statuses and change rates in functional ability (intercept variance = 13.53, $p < 0.001$; slope variance = 0.337, $p < 0.001$) and depressive symptoms (intercept variance = 5.868, $p < 0.001$; slope variance = 0.264, $p = 0.001$) over the four-year study period (Table 4). On average, participants' functional ability decreased significantly over time (−0.168, $p < 0.001$). The intercept of functional ability was positively associated with its slope (0.427, $p = 0.007$), showing that participants with better functional ability at baseline tended to experience a slower decline in functional ability over time. The mean initial score of depressive symptoms was 2.967 ($p < 0.001$). Among all participants, depressive symptoms dropped significantly over the four-year study period (−0.287, $p < 0.001$). Participants with more depressive symptoms at baseline tended to experience a significant decline of depressive symptoms over time (−0.613, $p < 0.001$).

The results of two conditional LGCM models (Tables 5 and 6) suggest that more social interactions among users (0.459, $p = 0.006$) and more users conducting physical activities (1.141, $p < 0.001$) in POS were positively associated with participants' functional ability at baseline. More types of leisure facilities (0.267, $p = 0.026$), more shade in POS (0.403, $P = 0.002$), and better accessibility (0.478, $p = 0.001$) were related to better functional ability at baseline. A higher proportion of social interaction among users in POS was associated with a more stable trajectory of functional ability among participants (0.09, $p = 0.028$) over time. More leisure facility types in POS were associated with slightly increasing functional abilities among participants (0.086, $p = 0.013$) during the study period. A higher percentage of shade in POS was associated with less decline in functional ability over time (0.091, $p = 0.009$). For depressive symptoms, however, significant associations between POS and participants' depressive symptoms were only found at baseline. Accessibility (−0.455, $p = 0.033$) was related to fewer depressive symptoms. The bench quality of POS (−0.279, $p = 0.054$) had a marginal association with fewer depressive symptoms. Surprisingly, the proportion of social interaction among users was related to more depressive symptoms at baseline (7.437, $p = 0.01$).

5. Discussion

To the best of our knowledge, this is the first study to examine longitudinal associations between POS environment quality, POS vitality, and older adults' functional ability and mental health. Accessibility of POS and social interaction among users in POS were related to better functional ability and fewer depressive symptoms among participants at baseline. The number of leisure facility types, shade, and social interaction among users in POS led to a slower decline of functional ability over time. However, there were no significant associations between POS and participants' depressive symptoms over time.

POS environment quality and vitality have exerted significant cumulative impacts. Participants tended to have better functional ability at baseline and undergo a slower decline in functional ability over time when residing in a neighborhood surrounded by POS characterized by more social interaction among users, more types of facilities, and higher percentages of shade. Specifically, there are differences of 3.104 in baseline IADL scores and 0.382 in the decreasing rate of IADL scores over time between older adults living close to POS with good environmental quality and vitality than those residing near poor-quality and deserted POS. These differences reveal the cumulative protect effects of good-quality and vibrant POS as sampled older adults have lived in the same estates for more than 30 years. Therefore, our findings provide the basis for evidence-based POS built environment intervention within residential areas in promoting healthy aging. Findings also extend existing research [13,27] by revealing the long-term effects of good-quality POS in maintaining older adults' functional ability.

However, neither POS environment quality nor vitality was significantly related to changes in depressive symptoms over the four-year study period. The development of depressive symptoms is attributed to biological factors, personal vulnerabilities, and negative life events [63,64]. While these factors are directly linked to depressive symptoms, POS may indirectly influence older adults' depressive symptoms by altering their psychological process [65]. Specifically, POS provide an

Table 4
Two separate unconditional latent growth curve models.

	LGCM for physical functional ability			LGCM for depressive symptoms		
	Estimate	S.E.	*p*	Estimate	S.E.	*p*
Means						
Intercept	14.871	0.09	<0.001	2.967	0.071	<0.001
Slope	−0.168	0.028	<0.001	−0.287	0.029	<0.001
Variances						
Intercept	13.533	0.555	<0.001	5.868	0.395	<0.001
Slope	0.337	0.069	<0.001	0.264	0.08	0.001
Covariance						
Intercept-slope	0.427	0.158	0.007	−0.613	0.151	<0.001
χ2	4.48		>0.05	26.532		<0.001
RMSEA	0.000			0.046		
CFI	1.000			0.981		
TFL	1.000			0.977		
SRMR	0.014			0.031		

Table 5
Longitudinal associations between POS and functional ability of older adults.

	Model 5			
	Intercept		Slope	
	β	P-Value	β	P-Value
POS vitality				
Diversity of age groups (Weighted)	0.053	0.717	0.017	0.683
Proportion of social interactions among users (Weighted)	0.459	0.006	0.09	0.028
Proportion of users conducting physical activities (Weighted)	1.141	<0.001	−0.065	0.055
POS environment quality				
Types of facilities (Weighted)	0.267	0.026	0.086	0.013
Percentage of shading of POS (Weighted)	0.403	0.002	0.091	0.009
Accessibility for older wheelchair users (Weighted)	0.478	0.001	0.067	0.053
Bench quality of POS (Weighted)	0.092	0.468	−0.026	0.517
Terrain slope	−0.001	0.515	−0.001	0.222
Covariates				
Neighborhood-level median monthly family income)	1.294	<0.001	0.007	0.912
Age	0.025	0.396	−0.018	0.059
Sex (Ref: Male)				
Female	0.279	0.393	−0.058	0.589
Self-rated health	0.914	0.007	−0.026	0.817
Number of chronic diseases (Ref: Two and more types of chronic disease)				
No chronic disease	−0.084	0.15	−0.016	0.419
Having one type of chronic disease	−0.013	0.899	−0.043	0.204
Education attainment (Ref: Primary school and below)				
Secondary	0.059	0.002	0.002	0.972
Associate and above	−0.898	0.485	0.016	0.969
Marital status (Ref: Single, divorced, separated, and widowed)				
Married	0.004	0.609	0.003	0.222
N	2081			
CFI	0.997			
RMSEA	0.012			
SRMR	0.006			

Notes: (1) Unstandardized estimates. (2) VIF<10.

Table 6
Longitudinal associations between POS and depressive symptoms of older adults.

	Model 6			
	Intercept		Slope	
	β	P-Value	β	P-Value
POS vitality				
Diversity of age groups (Weighted)	−4.227	0.165	0.576	0.667
Proportion of social interactions among users (Weighted)	7.437	0.01	−0.802	0.526
Proportion of users conducting physical activities (Weighted)	0.406	0.7	−0.533	0.254
POS environment quality				
Types of facilities (Weighted)	−0.066	0.666	0.03	0.658
Percentage of shading of POS (Weighted)	0.963	0.195	0.188	0.564
Accessibility for older wheelchair users (Weighted)	−0.455	0.033	0.062	0.506
Bench quality of POS (Weighted)	−0.279	0.054	0.073	0.25
Terrain slope	−0.006	0.555	0.002	0.602
Covariates				
Neighborhood-level median monthly family income)	0.066	0.847	−0.157	0.295
Age	0.011	0.305	0.003	0.458
Sex (Ref: Male)				
Female	0.259	0.081	−0.01	0.883
Cognitive function at baseline	−0.13	<0.001	0.022	0.001
Number of chronic diseases (Ref: Two and more types of chronic disease)				
No chronic disease	−1.398	<0.001	0.313	<0.001
Having one type of chronic disease	−0.889	<0.001	0.176	0.013
Education attainment (Ref: Primary school and below)				
Secondary	0.328	0.059	−0.08	0.287
Associate and above	0.045	0.924	0.014	0.944
Marital status (Ref: Single, divorced, separated, and widowed)				
Married	−0.12	0.434	0.043	0.527
N	2081			
CFI	0.901			
RMSEA	0.025			
SRMR	0.022			

Notes: (1) Unstandardized estimates. (2) VIF<10.

arena for older adults to recover from daily stress and develop supportive relationships with neighbors, thus protecting them against the adverse impacts from life event stressors. The indirect impact of POS on older adults' mental health may take longer to become evident. The significant associations between two POS indicators (i.e., accessibility and bench quality) and older adults' depressive symptoms at baseline support this possibility. The association indicates that older adults residing near good-quality POS tend to have fewer depressive symptoms than their counterparts living in close proximity to poorer-quality POS. This can be attributed to the indirect long-term impact of POS since most participants had lived in their neighborhood for several decades at the time of the survey. Consistent with Francis and his colleagues' findings [3], this study further indicates that the presence of POS within local neighborhoods may yield long-term rather than short-term mental health benefits for older residents.

In sum, this study sheds light on the Healthy Aging Research Framework by revealing the long-term effects of POS environment quality and vitality on older adults' physical and mental health. It has four research contributions. First, it develops innovative methods by pioneering a novel measurement tool to assess POS vitality with data collected from environment quality evaluation and space use behavior observation. This measurement tool can also be applied to other POS research. Second, it provides new insights into the Healthy Aging Research Framework by demonstrating the extent to which good-quality and vibrant POS environments slow functional decline among older adults over time. Third, the high degree of homogeneity in POS facilities, design, and levels of supply, renders the results more sensitive to small changes in POS quality and vitality. Fourth, it mitigates self-selection bias by using longitudinal data collected from the public rental housing neighborhoods in Hong Kong.

Our findings also have important implications for creating age-friendly physical environments in Chinese and neighbouring cities characterised by high population density. Healthy aging theory indicates that supportive POS can help older adults maintain or improve their functional ability even when confronted with adversity. Our findings offer practical insights for using POS as an intervention tool to facilitate older adults' healthy aging and enable local neighborhoods to adapt to population aging. Specifically, our findings emphasize that strategies using POS in local neighborhoods to facilitate older adults' functional ability and mental health should focus on both POS environment quality and vitality. We should first ensure facilities, shade, bench quality, and accessibility to create vibrant POS for older adults. In the daily management of POS, it is essential to review and manage these critical aspects constantly. Creating quality POS is not only by providing good-quality facilities, but also by increasing POS capacity to accommodate various users and activities. Public and private sectors that manage POS can focus on these aspects to gauge the vitality performance of POS. Besides, neighborhood leisure and cultural events can be held in POS to improve the popularity and vitality of POS. Second, we should encourage older adults to use POS as arenas for physical activities and socializing. POS can be conceived as an intervention site enabling older adults to participate in health-related activities conducive to their functional ability. Well-designed POS can promote active aging activities and aging in place.

There are three limitations of this research. Firstly, we did not evaluate safety or aesthetic characteristics when conducting community auditing in the sampled POS due to the research design. These components may influence POS vitality and older adults' functional ability. Secondly, we did not control other individual-level factors in the analysis, such as psychosocial attitudes, that may also explain the association between POS and older adults' functional ability and mental health. Thirdly, since study participants resided in public rental housing neighborhoods, it may be difficult to generalize the study results to older adults from other social groups.

6. Conclusion

This is the first study to apply the Ecological Model of Aging and the Healthy Aging Research Framework to examine the casual relationships between POS environment quality, POS vitality, and older adults' functional ability and mental health over time. It contributes to existing understanding by highlighting the impact of good-quality and vibrant POS environments on slowing functional decline among older adults over time. The indirect positive impact of POS on older adults' mental health may take longer to become evident. This study indicates that small changes of either POS environment quality or POS vitality can significantly protect older adults from functional decline and depressive symptoms. Therefore, it has strong practical implications for urban planners, policymakers, social workers, and psychologists for using POS as an intervention tool to facilitate older adults' healthy aging and enabling local neighborhoods to adapt to population aging. Specifically, our findings emphasize that strategies using POS in local neighborhoods to facilitate older adults' functional ability and mental health should focus on both POS environment quality and vitality. Well-designed POS can enable active aging activities and promote aging in place.

CRediT authorship contribution statement

Yuqi Liu: Methodology, Formal analysis, Conceptualization, Writing - original draft, Writing - review & editing. **Yingqi Guo:** Methodology, Validation. **Shiyu Lu:** Methodology. **On Fung Chan:** Investigation. **Cheryl Hiu Kwan Chui:** Writing – review & editing. **Hung Chak Ho:** Methodology. **Yimeng Song:** Methodology. **Wei Cheng:** Methodology. **Rebecca Lai Har Chiu:** Writing – review & editing, Resources. **Chris**

Webster: Writing – review & editing, Resources. **Terry Yat Sang Lum:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

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