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Original Research

How do forms and characteristics of Asian public housing neighbourhoods affect dementia risk among senior population? A cross-sectional study in Hong Kong

H.C. Ho [a, b, *], Y. Song [c], W. Cheng [d], Y. Liu [e], Y. Guo [f], S. Lu [g], T. Lum [h, i], R.L.H. Chiu [d, **], C. Webster [b, j]

[a] Department of Anaesthesiology, School of Clinical Medicine, The University of Hong Kong, Hong Kong, China
[b] Healthy High Density Cities Lab, The University of Hong Kong, Hong Kong, China
[c] School of the Environment, Yale University, New Haven, CT, 06511, United States
[d] Department of Urban Planning and Design, The University of Hong Kong, Hong Kong, China
[e] Department of Urban Planning, School of Architecture, South China University of Technology, Guangzhou, China
[f] Department of Social Work, Hong Kong Baptist University, Hong Kong, China
[g] Department of Social and Behavioural Sciences, City University of Hong Kong, Hong Kong, China
[h] Sau Po Centre on Ageing, The University of Hong Kong, Hong Kong, China
[i] Department of Social Work and Social Administration, The University of Hong Kong, Hong Kong, China
[j] Faculty of Architecture, The University of Hong Kong, Hong Kong, China

A R T I C L E I N F O

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A B S T R A C T

Background: Public housing estate is a key determinant of community health risk in American/European cities. However, how forms/characteristics of compact/hilly public housing's neighbourhoods affect dementia among Asian seniors was underestimated.
Design: This was a cross-sectional study.
Methods: A total of 2,077 seniors living in Hong Kong's public housing estates were included. Dementia was measured by a Cantonese version of Montreal – Cognitive Assessment. Built environment was measured based on three dimensions (greenery, walkability, accessibility), including 11 metrics. Circular buffers (without walking paths) and service areas (considering walking paths) with two-dimensional/three-dimensional (terrain) adjustment were applied to quantify forms/characteristics of neighbourhoods. Two spatial buffers were applied: immediate distance (200 m) and walkable distance (500 m). Exposure-by-exposure regressions were applied to evaluate the associations between form/characteristics of neighbourhood and dementia.
Results: Forms/characteristics without considering walking paths may overestimate health benefits from built environment. For circular buffers, higher percentage of building coverage, higher land use mix and more community/transportation/leisure facilities were negatively associated with dementia. All measures of greenery were positively associated with dementia. For service areas, measures of walkability and accessibility became insignificant except more community facilities at the immediate distance. Furthermore, terrain effect was insignificant when it was compared with the impacts of walking paths.
Conclusion: Dementia among seniors in hilly public housing estates was negatively associated with neighbourhood's walkability and accessibility and was influenced by walking paths. For healthy ageing, improved forms/characteristics of public housing neighbourhoods should include more accessible spaces and community facilities along walking paths for physical activities and basic daily needs.

Introduction

"Public housing estate" was originally conceived for pragmatic reasons.[1] Housing estate tended to fulfil basic living, with limited health/social support for vulnerable people (e.g. seniors). Public

* Corresponding author. Department of Anaesthesiology, School of Clinical Medicine, The University of Hong Kong, Hong Kong
** Corresponding author. Department of Urban Planning and Design, The University of Hong Kong, Hong Kong.
E-mail addresses: hcho21@hku.hk (H.C. Ho), rlhchiu@hku.hk (R. Chiu).

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housing residents even in high-income countries were associated with health issues.[2,3]

Seniors with dementia could be more vulnerable among all subpopulations. As a common disorder related to senior's cognitive function in high-income countries,[4] dementia could directly influence self-management, physical activities and daily living,[5,6] resulting in unhealthy diet, low levels of mobility and physical activity. Recent studies have investigated the association between built environment and dementia among seniors based on the following dimensions: greenery, building form and local accessibility.[7–10] However, few studies have evaluated these environment–health relationships in public housing estates, perhaps because of their physical homogeneity in American/European cities. Thus, the socioenvironmental nexus of low-income housing estates influencing residents' dementia needs to be investigated.

Specifically, housing estates in Asian cities are not as homogeneous as those in European/American cities. Hilly terrain and compact environment may vary the environment–health associations. This living environment can be stressful. Seniors constitute the least mobility among all subpopulations, and their decreasing financial means may accentuate immobility. They are neighbourhood bound and are frequent users of local facilities for exercise and socialising. However, the "older residents" can be low socioeconomic status, and the earlier estates were generally of low quality and lacked community/health facilities. Thus, variations of forms and characteristics in these public housing estates could yield dementia risk among older residents.

This study evaluated how form/characteristics in public housing neighbourhoods may be associated with dementia among seniors in Hong Kong. Particularly, we evaluated whether slope/terrain and walking paths in hilly environment would yield the association between built environment and dementia.

Data and methods

Data collection

These data were retrieved from a baseline survey of an existing cohort.[23,24,31] After removing four subjects with invalid data, a total of 2,077 subjects were included.

Specifically, the cohort study was originally conducted between 2014 and 2017, with participants aged ≥65 years living in 12 selected estates managed by Hong Kong Housing Society (Fig. 1). These included estates in urbanised areas and suburbs. More than half of these estates were located in the hilly environment (Fig. 2).

For baseline survey, all subjects were Cantonese-speaking Chinese tenants interviewed in 2014 and were randomly sampled within the following age strata: 65–74, 75–84 and ≥85. The target sample sizes for these age strata were 50, 60 and 70, respectively, resulting in a total of 180 subjects per estate. Oversampling for 75–84 and ≥85 years were taken into account due to the higher attrition rates. In addition, all interviews were conducted during home visits by trained researchers. More information regarding data collection's procedures has been noted in previous studies.[23]

Data collection was approved by the Human Research Ethics Committee, The University of Hong Kong (No: EA050814). All participants signed a written informed consent.

Health outcome

Dementia was measured based on a Cantonese version of Montreal – Cognitive Assessment.[11] Subjects with Cantonese version of Montreal – Cognitive Assessment ≤19 were with dementia symptoms.

Forms/characteristics of neighbourhoods

Four types of neighbourhoods were determined: (1) two-dimensional/three-dimensional (2D/3D) circular and (2) 2D/3D service area. *Circular* is a traditional measurement of neighbourhood based on a circular buffer drawn from the central point of a building. Environmental characteristics within the buffer were included without consideration of walking paths. *Service area* was an advanced measurement based on walking paths. 2D buffers did not adjust for slope/terrain. 3D buffers were with terrain adjustment. Two different scales were applied to determine the living environment: immediate distance (200 m) and walkable distance (500 m) from their residence. Immediate distance was associated with approximately six minute walk of seniors in Hong Kong. Walkable distance was associated with approximately 15-min walk. The above buffers have been used in other local studies.[21–24]

Built environment metrics

Built environment were measured based on the following dimensions: greenery, walkability and accessibility (Fig. 3).

Measures of Greenery included (1) % greenery, (2) greenness and (3) green heterogeneity. *%greenery* referred to percentage of natural greenery. It was mapped with a supervised classification with Google Earth Engine.[12] *Greenness* referred to the intensity of natural greenery and was calculated by the average of Normalized Difference Vegetation Index (NDVI). NDVI was calculated from red and near-infrared bands of a 2016 SPOT-6 multispectral satellite image.[13] Higher NDVI indicated more greenness. *Green heterogeneity* represented the mixture of natural greenery/non-greenery.[14] This measure was estimated based on the standard derivation of NDVI.

Measures of walkability included (1) %public space, (2) %building coverage and (3) land use mix. All measures were associated with Jane Jacob's theory of vitality and diversity.[15] *%public space* represented vitality and diversity of public open space designed and managed by the local government, including spaces for leisure, culture and sport activities. Higher percentage of public space implied a neighbourhood with better social connection and mobilisation. *%building coverage* represented the percentage of building footprint. According to Jacob's theory, small building blocks could enhance physical and social contacts among people, and sufficient concentration of buildings could sustain social connection. *Land use mix* was estimated by the equation noted elsewhere.[16] Five types of land use were included: residential lands, commercial/industrial lands, institutional lands, public space and others. Land use mix indicated diversified building types/services and attraction to walk around the neighbourhoods. Greater land use mix indicated higher walkability. All walkability measures were retrieved from Hong Kong's 1:1000 topographic (ib1000) map (https://data.gov.hk/en-data/dataset/hk-landsd-openmap-development-hkms-digital-b1k).

Measures of accessibility included (1) major transportation facilities, (2) facilities for municipal services, (3) community facilities, (4) leisure facilities and (5) health facilities. The spatial information was retrieved from the Hong Kong's GeoCommunity Database 3.0.

We set intervals of %greenery, %public space and %building coverage as 10% and intervals of greenness, green heterogeneity and land use mix as 0.1.

Covariates

Following our prior study using the same cohort,[31] covariates of medical history included cardiovascular disease, stroke, osteoporosis, chronic obstructive pulmonary disease, pain, depression,

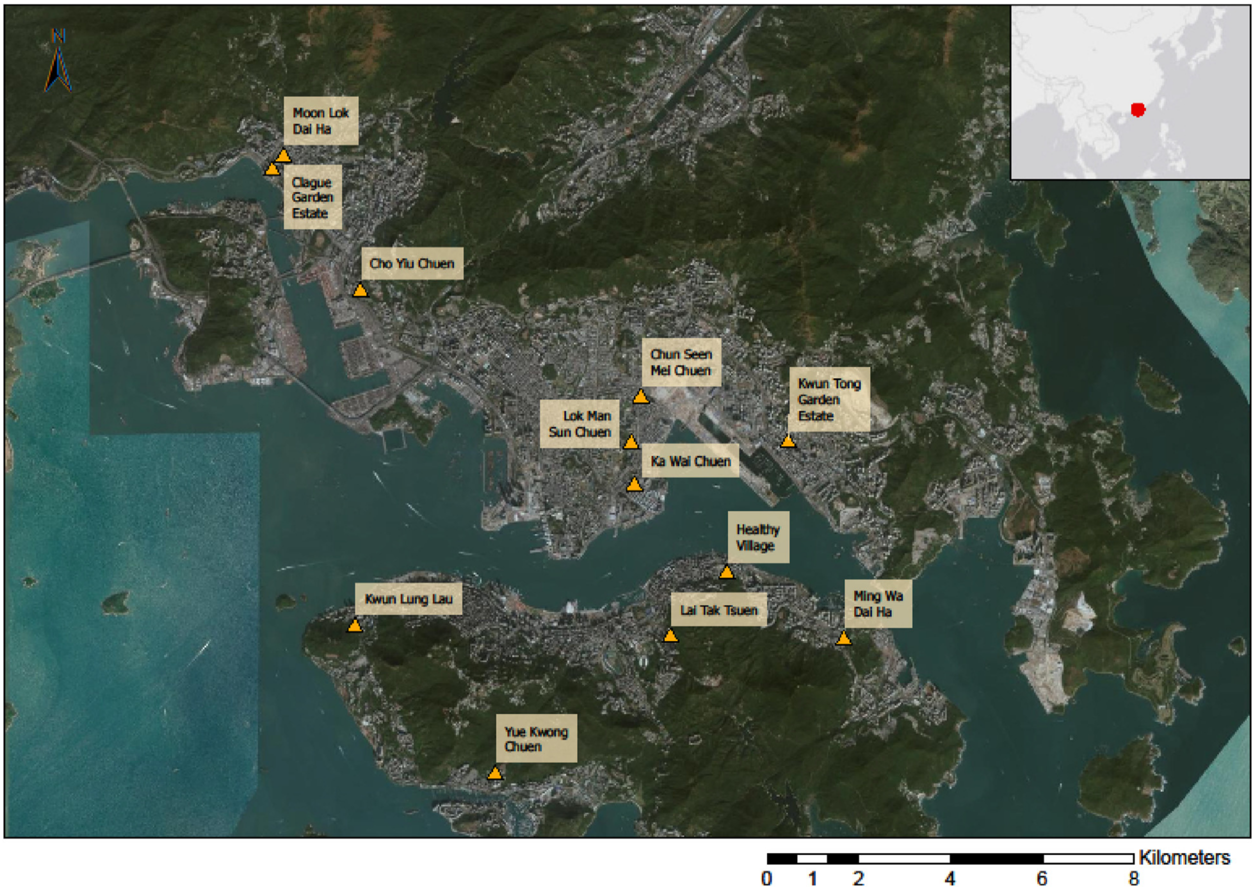

Fig. 1. Study area: twelve selected public housing estates in Hong Kong.

Fig. 2. Hilly environment of the selected public housing estates. Lai Tak Tsuen (left) is a public housing estate in a suburb near a middle-class neighbourhood. Cho Yiu Chuen (middle) is a public housing estate in a new town. Kwun Tong Garden Estate (right) is a public housing estate in an urbanised area near a low-income neighbourhood and industrial area.

walking ability and frailty. Depression was measured based on a Chinese version of Geriatric Depression Scale-15.[17] Frailty was estimated by the five item FRAIL Questionnaire.

Covariates regarding sociodemographic information and lifestyle characteristics included age, gender, body mass index (BMI), sleep quality, smoking status, alcohol consumption, low education, unhealthy diet, quality of life and activities of daily living. Quality of life was calculated based on the EUROHIS-QOL eight item index. The score of activities of daily living was calculated based on the Chinese version of Lawton Instrumental Activities of Daily Living scale (IADLs).[18] Low education was defined as individuals who only completed primary school or below .[19] Missing information was replaced with the average score of each measure.[20]

Statistical analyses

Exposure-by-exposure binomial regressions were used to evaluate the relationship between built environment metrics and

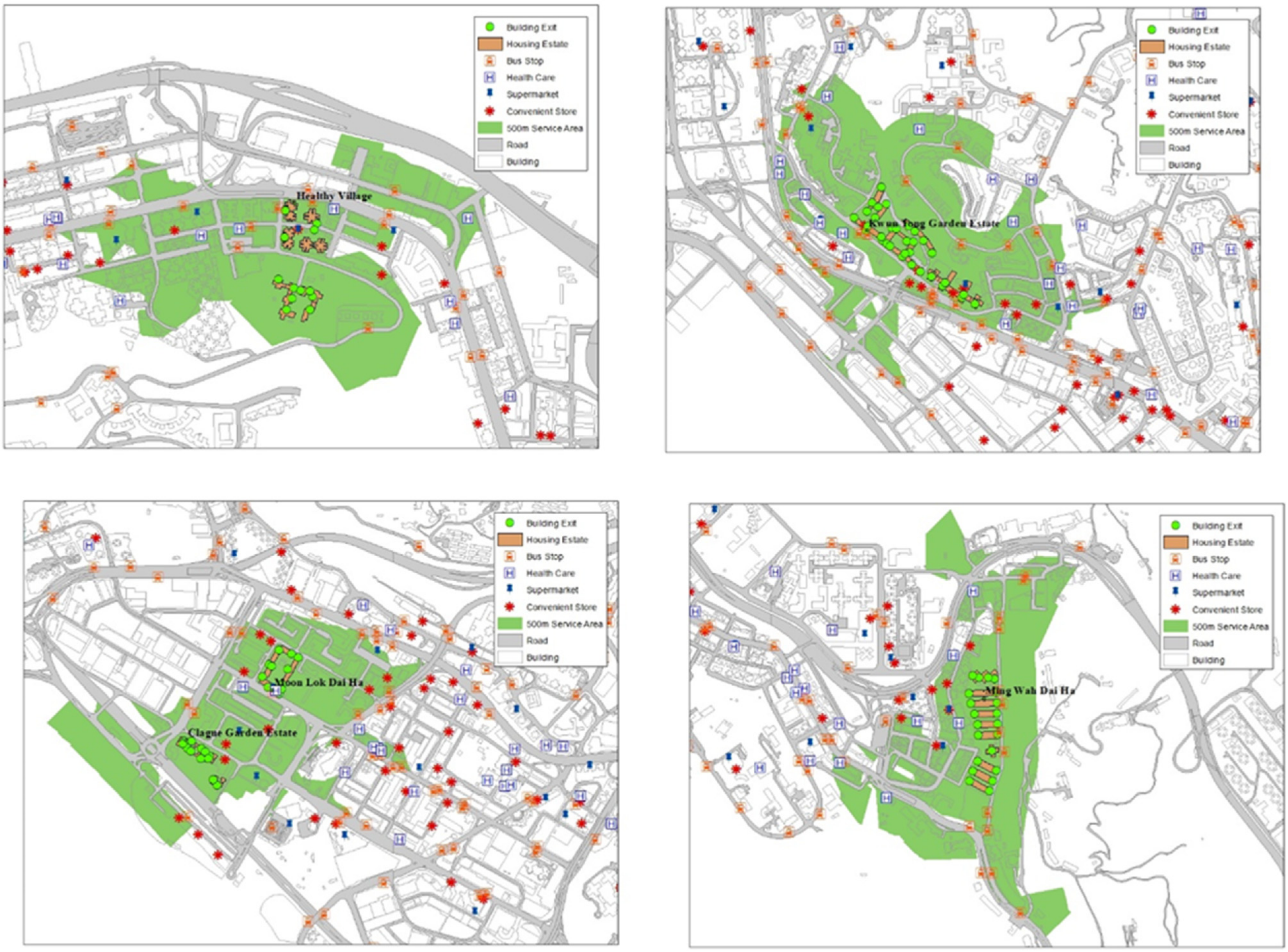

Fig. 3. Examples of greenery and facilities surrounding five of the 12 selected public housing estates. Healthy village (top left) and Ming Wah Dai Ha (bottom right) are public housing estates located in urbanised areas of Hong Kong Island. Kwun Tong Garden Estate (top right) is a public housing estate in an urbanised area near a low-income neighbourhood and industrial area of Kowloon. Clague Garden Estate and Moon Lok Dai Ha are public housing estates located in a new town of new territories.

dementia. Crude and adjusted odds ratios (ORs) for all regressions with 95% confidence intervals (CIs) were reported. Covariates regarding medical history, lifestyle and sociodemographic characteristics were selected based on Variance Inflation Factor <2 to minimise multicollinearity. Based on the results of Variance Inflation Factor, covariates for final models included IADLs, age, cardiovascular disease, stroke, chronic obstructive pulmonary disease, pain, depression, walking ability, frailty, low education, gender, BMI, quality of life, sleep quality, smoking status, alcohol consumption, unhealthy diet and osteoporosis. The previously mentioned factors were associated with dementia or cognitive functions.

Results

Data summary

Among 2,077 subjects, 859 subjects (41.4%) were associated with dementia (Table 1). These subjects were generally overweight (average BMI >23 kg/m^2). Subjects with dementia had significant differences in lifestyle and sociodemographic characteristics from those without dementia (Table 1). Particularly, the subjects with dementia were older ages (83.0 vs 77.3), more likely to be female (60.1% vs 55.2%), lower BMI (23.5 vs 23.8), less educated (88.4% vs 71.3%), lower quality of life (28.6 vs 29.31) and lower IADLs (13.8 vs 15.6). However, *t*-tests did not show significant differences in smoking status and alcohol consumption among subjects with and without dementia.

T-test results for medical history indicated that subjects with dementia were more associated with depression, lower ability to walk and frailty compared with subjects without dementia. About 12.8% of subjects with dementia found to have depressive symptoms, but only 9.2% subjects without dementia were associated with depression (*P*-value <0.05). Approximately 14.3% subjects with dementia reported to have problems to walk independently, but only 8.3% subjects without dementia reported to have this issue (*P*-value <0.05). Approximately 16.5% of subjects with dementia were associated with frailty, but only 8.7% of subjects without dementia were associated with frailty (*P*-value <0.05).

Local characteristics of built environment

Without consideration of walking paths and terrain/slope, all subjects were living in a high-density environment with mixed land uses (Table 2). The results of 2D circular buffers showed that the seniors of public housing estates were living with average 27.1% building coverage, 33.2% greenery and 8% public spaces within a 500-m radius. The land use mix within 500 m was 0.64, indicating a multifunctional neighbourhood. There were mostly more than two facilities for municipal services (e.g. bazaar, cooked fool stall,

Table 1
Summary of lifestyle and sociodemographic characteristics and medical history of all subjects (N = 2,077) in the analytic data set.

Dimension	Variable	With dementia	Without dementia	*t*-test
		n = 859	*n* = 1,218	*P*-value
Lifestyle and sociodemographic characteristics	Age	**83.0**	**77.3**	**<0.05**
	Gender	**60.1%**	**52.2%**	**<0.05**
	BMI	**23.5**	**23.8**	**<0.05**
	Sleep quality	16.5%	14.7%	0.26
	Smoking status	7.0%	7.0%	0.996
	Alcohol consumption	0.8%	1.5%	0.15
	Low education	**88.4%**	**71.3%**	**<0.05**
	Unhealthy diet	3.7%	4.5%	0.37
	Quality of life	**28.6**	**29.3**	**<0.05**
	Instrumental activities of daily living (IADLs)	**13.8**	**15.6**	**<0.05**
Medical history	Cardiovascular disease	18.3%	16.8%	0.40
	Stroke	7.6%	6.1%	0.19
	Chronic obstructive pulmonary disease	1.0%	0.9%	0.74
	Pain	9.4%	8.0%	0.27
	Depression	**12.8%**	**9.2%**	**<0.05**
	Walking ability	**14.3%**	**8.3%**	**<0.05**
	Frailty	**16.5%**	**8.7%**	**<0.05**
	Osteoporosis	11.5%	12.0%	0.75

Bold values indicate a significant difference between subjects with and without physical/cognitive functions based on t-test.

Table 2
Summary: local characteristics of built environment among all subjects (N = 2,077) in the analytics.

Built environment	2D circular				3D service area			
	Minimum	Maximum	Mean	SD	Minimum	Maximum	Mean	SD
Greenery (200 m)	3.6%	66.5%	**29.9%**	16.6%	1.0%	36.8%	**16.8%**	10.3%
Greenery (500 m)	8.0%	68.9%	**33.2%**	20.5%	5.8%	56.7%	**26.9%**	15.0%
Greenness (200 m)	0.14	0.57	**0.32**	0.11	0.15	0.40	**0.25**	0.07
Greenness (500 m)	0.15	0.59	**0.33**	0.14	0.15	0.51	**0.30**	0.10
Green heterogeneity (200 m)	0.09	0.30	**0.22**	0.06	0.07	0.25	**0.16**	0.05
Green heterogeneity (500 m)	0.14	0.32	**0.24**	0.06	0.11	0.29	**0.21**	0.06
% Public space (200 m)	0.0%	31.9%	**6.9%**	6.2%	0.0%	24.5%	**4.9%**	7.4%
% Public space (500 m)	1.0%	27.0%	**8.0%**	6.9%	0.5%	25.7%	**5.2%**	4.9%
% Building coverage (200 m)	10.6%	47.7%	**29.2%**	9.0%	18.5%	45.5%	**30.4%**	6.9%
% Building coverage (500 m)	11.3%	43.7%	**27.1%**	10.5%	11.3%	46.3%	**30.4%**	8.3%
Land use mix (200 m)	0.47	0.89	**0.70**	0.09	0.24	0.98	**0.72**	0.17
Land use mix (500 m)	0.48	0.84	**0.64**	0.08	0.55	0.84	**0.69**	0.08
Major transportation (200 m)	0	9	**2.5**	2.8	0	7	**0.7**	1.3
Major transportation (500 m)	2	20	**10.4**	5.5	0	12	**3.8**	3.3
Municipal services (200 m)	0	4	**0.8**	1.0	0	1	**0.1**	0.3
Municipal services (500 m)	0	5	**2.6**	1.4	0	4	**1.3**	1.2
Community facilities (200 m)	4	28	**14.8**	6.5	0	13	**5.5**	3.6
Community facilities (500 m)	26	84	**57.1**	14.3	8	47	**23.8**	9.8
Leisure facilities (200 m)	1	14	**6.2**	2.7	0	6	**1.5**	1.6
Leisure facilities (500 m)	11	57	**30.2**	9.5	1	18	**8.2**	3.6
Health facilities (200 m)	0	8	**2.2**	2.2	0	5	**0.6**	1.1
Health facilities (500 m)	0	21	**11.0**	5.6	0	10	**4.2**	3.1

2D, two-dimensional; 3D, three-dimensional; SD, standard deviation.
Two definitions of neighbourhoods separately applied to measure the local characteristics.

municipal complex, market, refuse collection point, toilet, wholesale market) within this walkable distance, as well as multiple spots of major transportation facilities, community facilities, leisure facilities and health facilities.

Considering walking paths and terrain/slope, all subjects were actually living in a more compact environment than the estimations from 2D models. The results of 3D services showed that seniors were living with averagely 30.4% building coverage, 26.9% greenery and 5.2% public spaces within a 500-m radius. Compactness did not eliminate land use diversity. Land use mix within 500 m was 0.69, which was even higher than the value calculated based on 2D circular. Furthermore, seniors averagely had at least one facility of municipal service within walkable distance. The number of other types of facilities was significantly lower than the results of 2D circular. However, there was still at least one spot of each type of facility within the walkable distance.

Built environment and dementia

There were significant differences in results when we compared the groups of circular buffers and service areas. Without consideration of walking paths (2D/3D circular), most measures related to walkability and accessibility were negatively associated with dementia (Table 3). Higher %building coverage in an immediate distance and a walkable distance were negatively associated with dementia (adjusted ORs for 2D circular: 0.90 [0.80, 0.998], 0.88 [0.80, 0.96]). Higher land use mix in a walkable distance was also negatively associated with dementia (adjusted OR for 2D circular: 0.84 [0.75, 0.95]). Furthermore, more community facilities and major transportation facilities within an immediate distance/walkable distance and more leisure facilities within an immediate distance had negative association with dementia. However, when walking paths were considered (2D/3D service area), most

Table 3
Association between built environment and dementia.

Built environment	2D circular		2D service area		3D circular		3D service area	
	Crude OR	Adjusted OR	Crude OR	Adjusted OR	Crude OR	Adjusted OR	Crude OR	Adjusted OR
% Greenery (200 m)	**1.09 [1.04, 1.15]**	**1.11 [1.05, 1.18]**	1.04 [0.95, 1.13]	1.06 [0.97, 1.16]	**1.09 [1.03, 1.16]**	**1.12 [1.05, 1.19]**	1.04 [0.95, 1.13]	1.06 [0.97, 1.16]
% Greenery (500 m)	***1.09 [1.05, 1.14]***	***1.10 [1.05, 1.15]***	**1.11 [1.05, 1.18]**	**1.12 [1.05, 1.20]**	**1.10 [1.05, 1.14]**	**1.10 [1.05, 1.16]**	***1.11 [1.05, 1.17]***	***1.12 [1.05, 1.20]***
Greenness (200 m)	**1.14 [1.05, 1.23]**	**1.18 [1.08, 1.28]**	1.07 [0.94, 1.22]	1.13 [0.98, 1.30]	**1.13 [1.04, 1.23]**	**1.18 [1.08, 1.30]**	1.07 [0.94, 1.23]	1.13 [0.97, 1.31]
Greenness (500 m)	***1.13 [1.06, 1.20]***	***1.14 [1.07, 1.22]***	**1.16 [1.06, 1.26]**	**1.19 [1.08, 1.31]**	**1.13 [1.06, 1.21]**	**1.15 [1.07, 1.23]**	***1.15 [1.06, 1.26]***	***1.18 [1.07, 1.30]***
Green heterogeneity (200 m)	**1.29 [1.11, 1.48]**	**1.32 [1.13, 1.55]**	1.14 [0.96, 1.34]	1.20 [0.995, 1.44]	**1.27 [1.09, 1.47]**	**1.31 [1.12, 1.54]**	1.13 [0.96, 1.34]	1.20 [0.99, 1.44]
Green heterogeneity (500 m)	***1.30 [1.12, 1.50]***	***1.32 [1.13, 1.55]***	**1.35 [1.16, 1.58]**	**1.38 [1.16, 1.64]**	**1.31 [1.13, 1.52]**	**1.34 [1.14, 1.59]**	***1.34 [1.15, 1.57]***	***1.37 [1.15, 1.63]***
% Public space (200 m)	1.02 [0.88, 1.17]	0.96 [0.83, 1.13]	0.95 [0.85, 1.07]	0.97 [0.86, 1.13]	0.99 [0.84, 1.15]	0.95 [0.80, 1.12]	0.96 [0.85, 1.08]	0.99 [0.87, 1.13]
% Public space (500 m)	1.05 [0.92, 1.19]	1.02 [0.88, 1.17]	0.96 [0.80, 1.16]	0.94 [0.77, 1.14]	1.04 [0.92, 1.18]	1.01 [0.89, 1.16]	0.96 [0.80, 1.15]	0.94 [0.77, 1.14]
% Building coverage (200 m)	0.94 [0.85, 1.03]	**0.90 [0.80, 0.998]**	1.12 [0.99, 1.27]	1.02 [0.88, 1.17]	0.94 [0.86, 1.04]	0.91 [0.82, 1.00]	1.13 [0.99, 1.28]	1.03 [0.89, 1.18]
% Building coverage (500 m)	**0.90 [0.83, 0.98]**	**0.88 [0.80, 0.96]**	0.97 [0.87, 1.07]	0.93 [0.83, 1.04]	**0.90 [0.82, 0.98]**	**0.88 [0.80, 0.97]**	0.97 [0.87, 1.07]	0.93 [0.83, 1.05]
Land use mix (200 m)	0.997 [0.89, 1.11]	0.97 [0.86, 1.09]	0.9996 [0.95, 1.05]	0.99 [0.94, 1.05]	0.99 [0.91, 1.08]	0.99 [0.90, 1.10]	0.999 [0.95, 1.05]	0.99 [0.94, 1.05]
Land use mix (500 m)	**0.86 [0.77, 0.96]**	**0.84 [0.75, 0.95]**	0.91 [0.82, 1.02]	0.92 [0.82, 1.04]	**0.83 [0.74, 0.93]**	**0.80 [0.71, 0.91]**	0.91 [0.81, 1.02]	0.92 [0.81, 1.04]
Major transportation (200 m)	**0.97 [0.95, 0.9996]**	**0.97 [0.94, 0.995]**	0.97 [0.90, 1.04]	0.94 [0.87, 1.01]	**0.96 [0.92, 0.99]**	**0.95 [0.91, 0.99]**	0.97 [0.90, 1.04]	0.94 [0.87, 1.01]
Major transportation (500 m)	**0.98 [0.97, 0.997]**	**0.98 [0.97, 0.997]**	1.01 [0.99, 1.04]	1.00 [0.97, 1.03]	**0.98 [0.97, 0.999]**	**0.98 [0.96, 0.997]**	1.01 [0.99, 1.04]	1.00 [0.97, 1.03]
Municipal services (200 m)	1.00 [0.92, 1.10]	0.95 [0.86, 1.04]	1.11 [0.86, 1.45]	1.09 [0.82, 1.46]	1.01 [0.91, 1.13]	0.96 [0.85, 1.07]	1.11 [0.86, 1.45]	1.09 [0.82, 1.46]
Municipal services (500 m)	0.96 [0.90, 1.02]	0.94 [0.88, 1.01]	1.01 [0.93, 1.08]	0.98 [0.90, 1.06]	0.98 [0.91, 1.05]	0.96 [0.89, 1.04]	1.01 [0.93, 1.08]	0.98 [0.90, 1.06]
Community facilities (200 m)	0.99 [0.97, 1.00]	***0.98 [0.97, 0.998]***	**0.98 [0.95, 0.9998]**	**0.97 [0.94, 0.997]**	**0.98 [0.97, 0.996]**	**0.98 [0.96, 0.995]**	***0.97 [0.95, 0.997]***	***0.97 [0.94, 0.99]***
Community facilities (500 m)	0.99 [0.99, 1.00]	**0.99 [0.99, 0.999]**	0.997 [0.989, 1.01]	0.99 [0.98, 1.00]	**0.99 [0.98, 0.995]**	**0.99 [0.98, 0.99]**	0.997 [0.99, 1.01]	0.99 [0.98, 1.00]
Leisure facilities (200 m)	**0.97 [0.94, 0.99]**	**0.96 [0.94, 0.99]**	1.03 [0.98, 1.09]	1.01 [0.95, 1.07]	0.99 [0.95, 1.02]	0.97 [0.93, 1.01]	1.03 [0.98, 1.09]	1.01 [0.95, 1.07]
Leisure facilities (500 m)	0.997 [0.99, 1.01]	0.999 [0.99, 1.01]	0.99 [0.97, 1.02]	0.98 [0.96, 1.01]	1.00 [0.99, 1.01]	1.00 [0.99.1.02]	0.99 [0.97, 1.01]	0.98 [0.96, 1.01]
Health facilities (200 m)	1.01 [0.98, 1.05]	1.01 [0.97, 1.04]	1.06 [0.98, 1.15]	1.02 [0.94, 1.11]	1.01 [0.97, 1.06]	0.997 [0.95, 1.05]	1.06 [0.98, 1.14]	1.02 [0.94, 1.11]
Health facilities (500 m)	0.9997 [0.99, 1.01]	0.998 [0.98, 1.01]	1.02 [0.99, 1.05]	1.01 [0.98, 1.04]	1.01 [0.99, 1.02]	0.998 [0.98, 1.02]	1.02 [0.996, 1.05]	1.01 [0.98, 1.04]

2D, two-dimensional; 3D, three-dimensional; CI, confidence interval; OR, odds ratio.
Bold values indicate a significant result from a model for a specific type of neighbourhood measurement. Bold and italicised values indicate the result with consistency for a measure of built environment based on whether OR and 95% CI from all model.

measures of walkability and accessibility became insignificant, except community facilities. For 3D service area, adjusted OR for more community facilities at the immediate distance was 0.97 [0.94, 0.99].

All measures of greenery from all types of spatial buffers had positive associations with dementia. For 3D service area, 10% increase in greenery within a walkable distance was positively associated with dementia (adjusted OR: 1.12 [1.05, 1.20]). An increase by 0.1 in greenness and green heterogeneity also resulted in adjusted ORs of 1.18 (1.07, 1.30) and 1.37 (1.15, 1.63).

In addition, the results did not show significant differences when we compared 2D and 3D service areas. The results between 2D and 3D circular buffers also did not indicate significant differences. It indicated that terrain effect was insignificant when walking paths were included in modelling.

Discussion

This study used four forms/characteristics of neighbourhoods (2D/3D circular and 2D/3D service area) with two spatial distances (200 m and 500 m) to evaluate the association between built environment and dementia across hilly public housing estates in Hong Kong. Overall, measures of walkability and accessibility were negatively associated with dementia, but measures of greenery were positively associated with dementia. Specifically, public spaces were not associated with dementia, whereas leisure and transportation facilities as well as land use mix and building coverage were only significant in the case of circular buffers where no consideration was given to walking paths. In the case of service area by which attention was given to walking paths, the only significant result related to walkability and accessibility was the negative association between community facilities and dementia.

These results were somewhat consistent with dementia research in American cities. For example, neighbourhoods in North America with better community resources and higher proximity to public transport and public space were associated with slower rate of cognitive decline.[7] These findings have particular relevance to public housing estates in Asian metropolitans, as they were often more compact and more densely populated than cities in the West,[32] including denser networks of community facility provision and public transport services.

Our results were also somewhat consistent with local studies[9,24] and several studies in other Asian cities.[10,25] Specifically, Guo et al.[9] found that neighbourhood library accessibility and neighbourhood walkability in Hong Kong were negatively associated with dementia, but neighbourhood recreational accessibility was not associated with dementia. Liu et al.[25] conducted a large population-based study in Taiwan (n = 26,206) and found that community centre availability was significantly associated with 8% decreased odds for dementia. However, greenery was not associated with dementia. Echoing the above results as well as the discussion of Guo et al.,[9] the contradictory association of walkability and greenery/public space with dementia could be due to the unfriendly design of urban greenery. In our study area, natural greenery was an unfavourable and inaccessible environment mainly found on the hilly slope (Fig. 4). Furthermore, our descriptive statistics showed a great difference in percentages of greenery and public spaces from the circular and service area's results, which further implied that public spaces in Hong Kong may not necessarily be “green” and urban greenery may be inaccessible. This specific characteristic of Hong Kong has also been noted in recent studies.[22,26] In addition, our subjects with dementia were individuals with lower quality of life and IADLs. Subjects with dementia were also associated with depression, frailty and lower walking ability. Thus, rurality and inaccessibility as well as sense of fear could be reasons behind these results. Linking to local context, Hong Kong's hilly terrain and inaccessible greenery may negatively affect the seniors' fear and the motivation to move around, which further influencing their abilities of spatial navigation. As a result, dementia risk was increased.

Fig. 4. Example of inaccessible greenery on the hilly slope nearby the selected public housing estates.

Advancing from previous studies, we considered various forms/characteristics of neighbourhoods with/without terrain and walking path's adjustment. Our results indicated that neighbourhood mapping without considering walking paths (2D/3D circular) might over-highlight health benefits of local built environment. Although the differences in effect sizes between results in circular buffers and service areas were not large (<10%), bias in using circular buffers was still notable. Specifically, most built environment metrics found to be significantly associated with dementia in circular buffers were insignificant in 2D/3D service area's analyses. This indicated the needs in considering walking paths. Based on our results, community plans for the facilitation of health care and resources should focus on enhancing spatial navigation and physical activities among seniors. For better healthy living, we suggested that improvements regarding design of public housing estates should include building more community facilities, major transportation facilities and leisure facilities along walking paths. With the walking paths, negative effects of steep slopes could be minimised. Otherwise, the functionality of these facilities might be reduced because of inaccessibility even the spatial distance may be close.

Several limitations should be noted. First, we followed previous studies to use home address to map the living environment. However, activity spaces of urban population could be different from living environment surrounding home.[27,28] Previous studies also found differences in daytime and night-time human behaviours in Asian cities, which induced various scenarios of environmental inequality.[27] However, seniors generally had lower ability to walk and were more locally bound, especially those with dementia. Thus, using home address to map the neighbourhoods may still be appropriate.

Our subjects were Cantonese-speaking Chinese tenants without known psychiatric disorder due to a prescreening test. This prescreening excluded individuals medically diagnosed with dementia. As these patients had high difficulties in self-management, they would mostly be living in institutional settings or staying in indoor environments. As our study focused on the associations between outdoor environment and dementia, exclusion was considered appropriate.

We followed previous studies to assume a linear relationship between built environments and dementia. However, relationships between environmental factors (e.g. greenspace) and health outcomes could be non-linear[29] and may be mediated by other neighbourhood effects.[30] Path analysis and non-linear models should be considered to further explore the relationships between built environment and dementia.

Conclusions

We evaluated how forms/characteristics of hilly public housing neighbourhoods may affect the association between built environment and dementia among low-income seniors in Hong Kong. We found that walking paths could affect the results, and this effect was much more significant than influences from terrain. Along walking paths, more community facilities within an immediate distance were negatively associated with dementia, but more greenery, greenness and green heterogeneity within a walkable distance were positively associated with dementia. This indicated that a walkable neighbourhood with more spaces for physical activities as well as for meeting basic requirements of daily living (e.g. groceries, local healthcare) is needed. Furthermore, measurement of neighbourhood effect should be linked with local terrain and road networks so that community plans to optimise a self-managed lifestyle could be developed effectively and appropriately.

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