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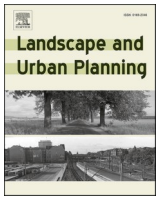

Depression among middle-aged adults in Japan: The role of the built environment design

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HIGHLIGHTS

- Perceived built attributes were associated with depressive symptoms.
- These associations differed between women and men.
- Perceptions of neighbourhood walkability are important for depression.

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ABSTRACT

There has been considerable interest in the effect of the built environment design on depressive symptoms. However, there are still few empirical studies on this topic, and there is a dearth of evidence among middle-aged adults. The present study examined the associations of urban design attributes with depressive symptoms among a sample of middle-aged adults in Japan. Cross-sectional data from a random sample of residents (40–64 years old) in two cities in Japan were examined. Depressive symptoms were assessed using the Centre for Epidemiological Studies Depression (CES-D) questionnaire. Two types of perceived and objective attributes of the built environment were measured. Covariate-adjusted multivariable linear and binary logistic models were used to estimate associations between perceived and objective built environment attributes and depressive symptoms. Among women, higher perceived access to public transport and total perceived walkability was associated with a decrease in depressive symptoms. Furthermore, there was a significant association between higher safety from traffic and lower odds of having mild depressive symptoms (CES-D $\geq$ 16) in women. Among men, higher safety from crime was associated with a decrease in depressive symptoms and with lower odds of having mild depressive symptoms. Total perceived walkability was also associated with lower odds of having mild depressive symptoms in men. None of the objective built environment attributes were associated with depressive symptoms in women or men. Our findings provide empirical evidence that improving perceptions of neighbourhood walkability and, in particular, enhancing access to public transport and safety from crime and traffic are important for improving depressive symptoms among middle-aged men and women.

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1. Introduction

Depression is one of the main chronic mental health disorders and is accompanied by numerous adverse effects on physical health and wellbeing (Ditmars et al., 2021; Ditmars et al., 2017; Sivertsen et al., 2015). It is estimated that approximately 280 million people of all ages have depression globally, including 5 % of adults and 5.7 % of older adults (Institute of Health Metrics Evaluation, 2019). Therefore, there has been an urgent call to reduce the global burden of depression worldwide (Herrman et al., 2019). Identifying modifiable factors that can help to prevent and manage depressive symptoms is necessary for developing effective interventions. The built environment's design, structure, facilities, and services impact residents' health and wellbeing. Several systematic reviews have presented evidence for the associations of the built environment with health and wellbeing outcomes (Malambo et al., 2016; Mazumdar et al., 2018; Nowak and Giurgescu, 2017).

Notably, there is increasing interest in this new area of inquiry on the role of the built environment on depressive symptoms (Barnett et al., 2018; Gong et al., 2016; Rautio et al., 2018). Several built environment features, such as urban greenness (Lu et al., 2021), population density (Wang et al., 2019), and proximate local destinations (Koohsari et al., 2019), were found to be associated with fewer depressive symptoms. Nevertheless, few studies have examined the relations between the built environment and depression (Barnett et al., 2018; Julien et al., 2012), and there is a dearth of evidence among middle-aged adults. Focusing on middle-aged adults is essential because this is a life phase when age-related functional decline and early signs of chronic diseases such as depression may begin to emerge (World Health Organization, 2002). In Japan, according to the patient survey conducted by the Ministry of Health, Labour, and Welfare (Japan Ministry of Health Labour and Welfare, 2019), the total number of inpatients and outpatients with mood and affective disorders (including manic depression) was approximately 1.2 million, of which 610,000 (approximately half) were aged 35–64 years. Furthermore, little evidence exists on how objective and perceived measures of the built environment may influence depression. Findings from studies with the objective and perceived built environment measures could be useful in (re)designing physical environment and developing individual and group health promotion programs to reduce depressive symptoms.

2. Literature review: the built environment design and depression

The built environment generally refers to "the human-made space in which people live, work, and recreate a day-to-day basis" (Saelens and Handy, 2008), such as houses, shops, roads, parks, and public spaces. Within the nudge theory and behavioural insights framework (Hallsworth and Kirkman, 2020; Thaler and Sunstein, 2009), the built environment has the potential to provide individuals with healthy behaviour choices (Sallis et al., 2012; Sarkar and Webster, 2017). Previous studies have provided conceptual frameworks explaining the pathways between the built environment and population health (Frank et al., 2003; Koohsari et al., 2020a; Northridge et al., 2003). Built environment attributes, including streets, parks, buildings, destinations, and residential density, are associated with several behaviours which can affect health, such as physical activity (Kärmeniemi et al., 2018), diet (Caspi et al., 2012), and sleep (Kim et al., 2022). While individual-based strategies to encourage people to improve these behaviours remain necessary, (re) designing the built environment can have a long-term effect on these behaviours among a large number of people over time (Chokshi and Farley, 2014).

Several systematic and narrative reviews have investigated the effects of the built environment on mental health (Beemer et al., 2021; Clark et al., 2007; Moore et al., 2018; Nordbø et al., 2018). Notably, previous studies have suggested the links between the built environment and psychological distress, such as anxiety and depression (Barnett et al., 2018; Gong et al., 2016; Mair et al., 2008; Rautio et al., 2018; Sokale et al., 2022). For instance, a systematic review investigating the effects of the living environment on depressive mood found that several built environment attributes such as housing quality, parks, and air/noise pollution were related to depression (Rautio et al., 2018). Another systematic review identified that the availability of green spaces had beneficial effects on depressive syndrome among older adults (Sokale et al., 2022). The built environment's effects on psychological distress, such as anxiety and depression, may be mediated through several pathways, such as air pollution (Fan et al., 2020), crime and incivilities (Curry et al., 2008), and the restorative effects of green and blue spaces (Yu et al., 2020). For example, in a systematic review and meta-analysis, Fan et al. (2020) found that short-term exposure to ambient air pollution (NO_2) was associated with depression. In particular, the positive impact of walking and social interactions on better mental health has been well-established (Mammen and Faulkner, 2013; Pemberton and Tyszkiewicz, 2016). Mammen and Faulkner (2013), in a systematic review of 30 prospective studies, found that higher levels of physical activity were associated with a lower risk of developing depression.

Notably, neighbourhood walkability has been suggested as a key dimension for the built environment-health relations (Frank et al., 2003). Several previous studies examined the associations between several walkable built environment attributes such as urban parks, street connectivity, and land-use mix with depression (Baranyi et al., 2021; Berke et al., 2007; Galea et al., 2005; Gariepy et al., 2014; Ivey et al., 2015; Koohsari et al., 2019; Lam et al., 2020; Lu et al., 2021; Mukherjee et al., 2017; Wang et al., 2019). For instance, a study conducted in the USA found that low neighbourhood walkability (objectively measured by geographic information systems) was associated with higher depressive symptoms in older men (Berke et al., 2007). Another study in the USA found that neighbourhood safety from crime and traffic was negatively associated with depressive symptoms among older adults (Ivey et al., 2015). In a study conducted in Hong Kong and Singapore, Lam et al. (2020) found that several objective and perceived built environment measures such as park size, street connectivity, and walkability were associated with lower depression among older adults. Another study in Japan found that high population density and proximate local destinations were negatively associated with older adults' depressive symptoms (Koohsari et al., 2019). Walkable built environments can influence people's depressive symptoms by creating a supportive environment for walking and social interactions (Tamura et al., 2020; Zhang et al., 2019). For example, a study conducted in Hong Kong found positive associations between several built environment attributes (e.g., street connectivity and pedestrian infrastructure) and depression among older adults were partially mediated by walking for transport (Zhang et al., 2019).

Nevertheless, most previous studies investigated the effects of objective, or perceived measures of walkable built environment attributes on depression. Evidence indicates a disagreement between objective and perceived measures of the built environment (Guo et al., 2021; Shatu et al., 2019). These findings suggest that objective and perceived measures may capture different aspects of walkable built environments and may differently influence residents' health behaviour and depression (Ma et al., 2014). It is then important to explore how objective and perceived measures of walkable built environments may affect depressive symptoms. Additionally, a limited number of studies conducted in diverse geographical and cultural contexts remain challenging in concluding the role of walkable built environments on depression. Notably, most previous studies focused on two age groups of children, adolescents, or older adults, with a lack of studies on middle-aged adults, a critical life stage (Barnett et al., 2018; Mair et al., 2008; Sokale et al., 2022). Thus, the current study aims to address these gaps. The research questions are as follows: (a) how does the built environment influence depressive symptoms among middle-aged adults? (b) what are the associations between objective and perceived measures of walkable built environments and depression?

3. Methods

3.1. Study participants and data source

This study is a secondary analysis of data from an epidemiological study undertaken to explore social and environmental determinants of health and wellbeing among middle-aged adults (aged 40–64 years) in Japan from July to December 2013 and from April 2014 to February 2015. Detailed recruitment and data collection procedures have been documented elsewhere (Ishii et al., 2018). Briefly, an invitation letter was mailed to 6,000 middle-aged adult residents living in two Japanese urban localities, Koto Ward (40.2 km^2; 484 000 people) and Matsuyama City (428.9 km^2; 516 000 people). Koto Ward is one of the 23 wards located within the Tokyo Metropolitan area, and Matsuyama City is a medium-sized regional city in southwest Japan (Fig. 1). Participants were randomly sampled from the Japan Basic Resident Register (i.e., government registry of residents) of residential addresses. Non-respondents were reminded by a second letter two weeks after the initial mailing. Those who agreed to participate in the study (866 individuals, response rate = 14.4 %) received a self-administered questionnaire. This questionnaire included questions about sociodemographic variables (e.g., age, gender, education), health-related items, and perceived neighbourhoods. Those participants who completed the study (n = 779) were offered a book voucher (¥1000, equivalent to approximately US$10). All participants provided written informed consent. The Research Ethics Committee, Waseda University, Japan (2012–269) approved this study.

3.2. Measures

3.2.1. Depressive symptoms

Depressive symptoms were assessed using the Centre for Epidemiological Studies Depression (CES-D) scale (Radloff, 1977). A Japanese-translated version of the CES-D that has been validated for the Japanese population was used (Shima, 1985). The CES-D is a 20-item self-report questionnaire asking participants about the frequency of depressive symptoms during the past week on a four-point Likert scale. The CES-D has a minimum score of 0 and a maximum score of 60, with higher scores showing the presence of more depressive symptoms. A cut-off score of ≥16 was used to detect the presence of clinically relevant depressive symptoms (Radloff, 1977). We also examined the CES-D continuous score as an outcome.

3.2.2. Perceived built environment attributes

The perceived built environment attributes were evaluated using the Japanese-translated version of the International Physical Activity Questionnaire Environmental Module (Inoue et al., 2009; Sallis et al., 2009). Good test–retest reliability of these questionnaire items has been demonstrated (kappa ranging from 0.63 to 0.97) for the Japanese population (Inoue et al., 2009). Ten items were included: population density, access to shops, access to public transport, presence of sidewalks, presence of bike lanes, access to recreational facilities, safety from crime, safety from traffic, social environment (referring to physical activity norms in the neighbourhood), and aesthetics (Table 1). For the population density question, the response options were detached single-family housing; apartments with 2–3 stories; a mix of single-family housing and apartments with 2–3 stories; condos with 4–12 stories; and condos with >13 stories. Participants answered the other questions using a four-point Likert scale (strongly agree, somewhat agree, somewhat disagree, and strongly disagree). The population density was categorised as 'low' (detached single-family housing) and 'high' (others). The other perceived measures were divided into 'high' (strongly agree and somewhat agree) and 'low' (somewhat disagree and strongly disagree) (Inoue et al., 2009). Safety from crime and traffic items were reverse coded before the analysis. In line with previous studies, total

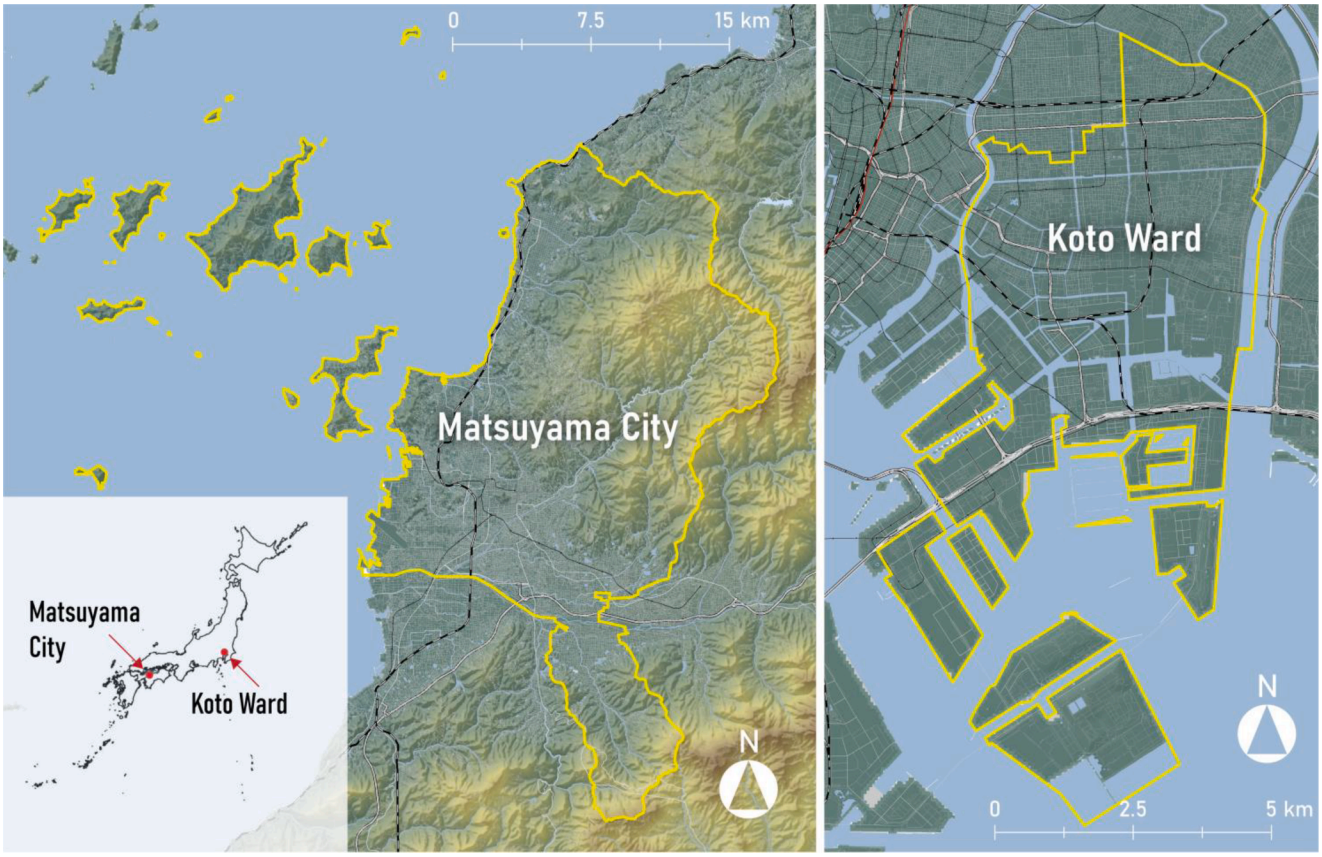

Fig. 1. The locations of Koto Ward and Matsuyama City in Japan.

Table 1
The perceived built environment attributes from the Japanese translated of the International Physical Activity Questionnaire Environmental Module.

	Question Items (Inoue et al., 2009)
Population density	"What is the main type of housing in your neighbourhood?"
Access to shops	"Many shops, stores, markets or other places to buy things I need are within easy walking distance of my home."
Access to public transport	"It is within a 10–15 min walk to a transit stop (such as bus, train, trolley, tram) from my home."
Presence of sidewalks	"There are sidewalks on most of the streets in my neighbourhood."
Presence of bike lanes	"There are facilities to bicycle in or near my neighbourhood, such as special lanes, separate paths or trails, shared use paths for cycles and pedestrians."
Access to recreational facilities	"My neighbourhood has several free or low-cost recreation facilities, such as parks, walking trails, bike paths, recreation centres, playgrounds, public swimming pools, etc."
Safety from crime	"The crime rate in my neighbourhood makes it unsafe to go on walks at night."
Safety from traffic	"There is so much traffic on the streets that it makes it difficult or unpleasant to walk in my neighbourhood."
Social environment*	"I see many people being physically active in my neighbourhood. Physically active means doing things like walking, jogging, cycling, or playing sports and active games."
Aesthetics	"There are many interesting things to look at while walking in my neighbourhood."

* This item refers to physical activity norms in the neighbourhood.

perceived walkability was calculated by summing the ten perceived built environment attributes (each attribute was coded as low = 1 and high = 2), resulting in a possible range from 10 to 20. The questionnaire had high internal consistency (Cronbach's alpha = 0.72).

Objective built environment attributes. Three objective built environment attributes, including population density, number of intersections, and availability of destinations, were calculated using geographic information systems. These attributes were found to be associated with walking and physical activity behaviours (Farkas et al., 2019; Hajna et al., 2015; McCormack and Shiell, 2011). These attributes were calculated within two network-based buffers of 800 m and 1600 m around participants' geocoded residential addresses. The choice of these buffers was consistent with previous studies examining the role of the built environment on health behaviours and outcomes (Hirsch et al., 2014; Koohsari et al., 2020b). The source data for the population was the Half Grid Square of population census 2010, providing a population count for each approximately 500 m by 500 m grid cell. Population density is calculated by the estimated population size within the buffer area divided by the areal size of the buffer area. Water bodies and uninhabited grids within the buffer area were excluded from the calculation. The number of intersections referred to the total number of 3-way or more intersections within each buffer sourced from geographic information systems vector datasets made and revised by the Geospatial Information Authority of Japan (https://www.gsi.go.jp/common/000078705.pdf). The total number of nine types of public and private destinations within each buffer was calculated. These destinations included banks, bookstores, convenience stores, elementary schools, community centres, post offices, restaurants, supermarket/department stores, and sports/fitness clubs. The source data for destinations were the 2010–2013 National Land Numerical Information by the Ministry of Land, Infrastructure, Transport and Tourism (https://nlftp.mlit.go.jp/ksj-e/index.html) and geocoding the addresses recorded in the telephone directory as of October 2015. This study also included the Walk Score® as a composite objective measure of the built environment. Walk Score® is a free tool that assigns an objective score (low: 0 to high: 100) to any given spatial address (Walk Score, 2020). Its concurrent validity with objectively measured built environment measures in the Japanese environment has been reported elsewhere (Koohsari et al., 2018). Two independent research members entered each participant's residential address into the Walk Score® website (https://www.walkscore.com) and obtained Walk Score® values. Disagreements between the researchers were resolved by consulting the first author.

Covariates. Participants reported the following sociodemographic variables: age, gender (women, men), working status (employed, unemployed), educational attainment (tertiary or higher, below tertiary), marital status (single, couple), living status (alone, with others), gross annual household income (≤¥5,000,000, >¥5,000,000), and length of neighbourhood residence (years). A national deprivation indicator was linked to each participant's residential addresses to indicate area-level socioeconomic conditions (Nakaya et al., 2014). This index compromised the weighted sums of various poverty-related census variables (as of 2010), including unemployment rate, proportion of sales and service workers, proportion of agricultural workers, proportion of blue-collar workers, proportion of rented houses, proportion of elderly single households, proportion of single-mother households, and proportion of elderly couple households.

3.3. Statistical analysis

Descriptive statistics, including means and standard deviations as well as frequencies, were calculated for sociodemographic variables. Differences in characteristics between women and men were examined using Pearson's chi-square tests for categorical variables and independent t-tests for continuous variables. Gender-stratified multivariable linear and binary logistic models were used to estimate associations between perceived and objective built environment attributes and depressive symptoms. The models included each built environment variable separately to avoid collinearity issues. Normality assumptions were checked by quantile–quantile plots of the residuals. For all point estimates, unstandardised regression coefficients (b), odds ratios (OR), and 95 % confidence intervals (CI) were assessed. Before the regression analysis, each objective built environment attribute was standardised (i.e., z-scores). All models were adjusted for sociodemographic covariates (age, working status, educational attainment, living status, gross annual household income, length of neighbourhood residence, and neighbourhood socioeconomic status). A dichotomous area variable (Koto Ward and Matsuyama City) representing locality effects at the city level was also included as a covariate in all models. A complete case strategy was selected because the proportion of missing data was low (under 5 %) (Jakobsen et al., 2017). All inferential statistical tests were two-tailed and statistical significance was set at $p < 0.05$. Analyses were conducted using Stata 15.0 (Stata Corp, College Station, Texas).

4. Results

4.1. Characteristics of study participants

After excluding those with missing variables, data from 719 participants were included in this study. Table 2 shows the characteristics of the sample. The mean age was 52.1 years, 59.5 % were female, 83.4 % were employed, 64.3 % had completed tertiary or higher education, 79.8 % were a couple, 89.0 % lived with others, and 54.4 % had an annual gross household income lower than <¥5,000,000. The mean (±standard deviation) CES-D score was 10.4 ± 7.6 with a median of 9.0. A total of 18.5 % of participants had a CES-D ≥ 16 and were thus considered to have mild depressive symptoms. There were no significant differences between women and men in their level of depressive symptoms. Table 3 shows the mean scores of built environment attributes around participants' homes. There were no significant differences between women and men in their surrounding built environment attributes, except for safety from crime: 88.0 % of women reported high levels of safety from crime, while 79.0 % of men reported high levels of safety from crime ($p < 0.05$). There were significant ($p < 0.05$) Pearson's correlations between.

Table 2
Characteristics of study participants (N = 719).

Variable	Mean (SD) or N (%)	Women (n = 428)	Men (n = 291)	p[a]
Age (years)	52.1 (7.0)	51.9 (6.9)	52.3 (7.2)	0.4
Working status				
Employed	600 (83.4)	324 (75.7)	276 (94.8)	< 0.05
Unemployed	119 (16.6)	104 (24.3)	15 (5.2)	
Educational attainment				
Tertiary or higher	462 (64.3)	276 (64.5)	186 (63.9)	0.9
Below tertiary	257 (35.7)	152 (35.5)	105 (36.1)	
Marital status				
Single	145 (20.2)	105 (24.5)	40 (13.7)	< 0.05
Couple	574 (79.8)	323 (75.5)	251 (86.3)	
Living status				
Alone	79 (11.0)	48 (11.2)	31 (10.7)	0.9
With others	640 (89.0)	380 (88.8)	260 (89.3)	
Annual gross household income				
<¥5,000,000	391 (54.4)	221 (51.6)	170 (58.4)	0.1
≥¥5,000,000	328 (45.6)	207 (48.4)	121 (41.6)	
Length of neighbourhood residence (years)	15.7 (13.1)	15.8 (12.0)	15.6 (14.6)	0.8
Depressive symptom score (CES-D score)	10.4 (7.6)	10.5 (8.0)	10.2 (7.0)	0.6
Mild depressive symptoms (CES-D ≥ 16)				
Yes	133 (18.5)	82 (19.2)	51 (17.5)	0.6

[a] Based on independent *t*-test or Chi-squared test.

4.2. Associations between the built environment attributes and depressive symptoms

Tables 4 and 5 show the associations between the built environment attributes and depressive symptoms stratified by gender. Among women, after adjusting for all covariates, higher perceived access to public transport was associated with a decrease in depressive symptoms (b = -3.62, 95 % CI −6.48, −0.76, $p = 0.01$). Total perceived walkability was also negatively associated with depressive symptom scores (b = -0.52, 95 % CI −0.93, −0.10, $p = 0.01$). Furthermore, there was a significant association between higher safety from traffic and lower odds of having mild depressive symptoms (CES-D ≥ 16) among women (OR = 0.53, 95 % CI 0.30, 0.94, $p = 0.03$). Among men, after adjusting for all covariates, higher safety from crime was associated with a decrease in depressive symptoms (b = -4.21, 95 % CI −6.67, −1.76, $p = 0.00$) and with lower odds of having mild depressive symptoms (CES-D ≥ 16) (OR = 0.35, 95 % CI 0.15, 0.80, $p = 0.01$). Total perceived walkability was also associated with lower odds of having mild depressive symptoms (CES-D ≥ 16) in men (OR = 0.76, 95 % CI 0.62, 0.93, $p = 0.01$). None of the objective built environment attributes were significantly associated with depressive symptoms in women and men.

5. Discussion

This study is one of the few studies that have examined the associations of perceived and objective built environment attributes and depressive symptoms among middle-aged adults. We found that several perceived built environment attributes were associated with depressive symptoms, and these associations differed between women and men. This aligns with the broader idea that gender differences exist in the observed relationships between the built environment and health and wellbeing outcomes (Tcymbal et al., 2020; Valson and Kutty, 2018). Higher perceived access to public transport and safety from traffic was found to be negatively associated with women's depressive symptoms. Better access to public transport and safety from traffic may contribute to accumulating a higher level of daily walking behaviour, which may alleviate depressive symptoms (Chaix et al., 2019; Panter et al., 2019; Patterson et al., 2019). For example, a study conducted in France using sensor tracking and location-based data found that public transport trips were associated with higher distances of walking and step counts than entirely walked trips (Chaix et al., 2019). Public transport use may also facilitate social encounters and support the link between social interaction and depression (Green et al., 2014; Mah and Mitra, 2017).

Perceived safety from crime was negatively associated with men's depressive symptoms. This is consistent with a body of literature showing evidence of the harmful impact of neighbourhood crime on mental health outcomes, such as depression and anxiety (Baranyi et al., 2021). For example, a study conducted in the USA among older adults

Table 3
Participants' neighbourhood environmental attributes.

	N (%) or Mean (SD) or	Women (n = 428)	Men (n = 291)	p[a]
Perceived built environment				
Population density				
High	374 (52.0)	221 (51.6)	153 (52.6)	0.8
Access to shops				
High	521 (72.5)	319 (74.5)	202 (69.4)	0.1
Access to public transport				
High	656 (91.2)	396 (92.5)	260 (89.3)	0.1
Presence of sidewalks				
High	539 (75.0)	317 (74.1)	222 (76.3)	0.5
Presence of bike lanes				
High	244 (33.9)	142 (33.2)	102 (35.1)	0.6
Access to recreational facilities				
High	477 (66.3)	285 (66.6)	192 (66.0)	0.9
Safety from crime				
High	594 (82.6)	338 (79.0)	256 (88.0)	<0.05
Safety from traffic				
High	556 (77.3)	340 (79.4)	216 (74.2)	0.1
Social environment				
High	598 (83.2)	354 (82.7)	244 (83.8)	0.7
Aesthetics				
High	437 (60.8)	262 (61.2)	175 (60.1)	0.8
Total perceived walkability	16.95 (2.10)	16.95 (2.12)	16.95 (2.07)	1.0
Objective built environment				
Population density (people/km^2)				
Within 800 m buffer	2502.3 (3100.0)	2462.7 (3122.0)	2560.4 (3071.8)	0.7
Within 1600 m buffer	2311.0 (2866.2)	2262.7 (2871.2)	2382.1 (2862.3)	0.6
Number of intersections				
Within 800 m buffer	444.5 (201.0)	441.7 (199.2)	448.6 (203.9)	0.6
Within 1600 m buffer	1609.3 (708.2)	1598.7 (715.1)	1624.8 (698.9)	0.6
Availability of destinations				
Within 800 m buffer	92.3 (143.4)	94.4 (151.3)	89.1 (131.1)	0.6
Within 1600 m buffer	399.9 (444.9)	402.4 (441.5)	396.2 (450.6)	0.8
Walk Score®	72.9 (24.9)	73.2 (24.4)	72.5 (25.7)	0.7

[a] Based on the chi-squared test or independent samples *t*-test.

Table 4
Associations between built environment attributes and depressive symptom score.

	Depressive symptom score	
	Women (n = 428) b (95 % CI)	Men (n = 291) b (95 % CI)
Perceived built environment		
Population density		
High	−0.79 (-2.69, 1.12)	−0.02 (-2.25, 2.20)
Access to shops		
High	−0.01 (-1.81, 1.78)	0.54 (-1.34, 2.43)
Access to public transport		
High	−3.62 (-6.48, −0.76)*	1.18 (-1.58, 3.95)
Presence of sidewalks		
High	−0.68 (-2.60, 1.24)	0.64 (-1.54, 2.82)
Presence of bike lanes		
High	−0.73 (-2.35, 0.90)	0.30 (-1.43, 2.02)
Access to recreational facilities		
High	−0.47 (-2.36, 1.42)	−0.92 (-2.91, 1.07)
Safety from crime		
High	−1.32 (-3.16, 0.51)	−4.21 (-6.67, −1.76)*
Safety from traffic		
High	−1.53 (-3.38, 0.32)	−1.22 (-3.08, 0.65)
Social environment		
High	−1.74 (-3.73, 0.24)	0.17 (-2.08, 2.43)
Aesthetics		
High	−1.13 (-2.69, 0.43)	−0.53 (-2.28, 1.22)
Total perceived walkability	−0.52 (-0.93, −0.10)*	−0.21 (-0.71, 0.29)
Objective built environment		
Population density		
Within 800 m buffer	−0.35 (-1.52, 0.81)	0.73 (-0.57, 2.04)
Within 1600 m buffer	−0.09 (-1.27, 1.08)	0.52 (-0.79, 1.82)
Number of intersections		
Within 800 m buffer	−0.40 (-1.17, 0.36)	0.39 (-0.43, 1.20)
Within 1600 m buffer	−0.08 (-0.84, 0.68)	0.37 (-0.48, 1.22)
Availability of destinations		
Within 800 m buffer	0.35 (-0.39, 1.09)	0.22 (-0.75, 1.18)
Within 1600 m buffer	0.50 (-0.33, 1.34)	0.33 (-0.59, 1.25)
Walk Score®	0.03 (-0.88, 0.94)	0.39 (-0.56, 1.34)

Note: b = regression unstandardised coefficients; CI = confidence interval; all models adjusted for age, working status, educational attainment, marital status, living status, gross annual household income, length of neighbourhood residence, neighbourhood socioeconomic status, and locality.
*$p \leq 0.05$.

Table 5
Associations between the built environment attributes and having depression (CES-D ≥ 16).

	Depression	
	Women OR (95 % CI)	Men OR (95 % CI)
Perceived built environment		
Population density		
High	0.84 (0.44, 1.59)	0.68 (0.29, 1.63)
Access to shops		
High	1.13 (0.62, 2.05)	0.69 (0.33, 1.41)
Access to public transport		
High	0.62 (0.26, 1.46)	0.69 (0.26, 1.86)
Presence of sidewalks		
High	1.02 (0.54, 1.93)	0.74 (0.31, 1.77)
Presence of bike lanes		
High	0.59 (0.33, 1.05)	0.72 (0.36, 1.44)
Access to recreational facilities		
High	0.90 (0.48, 1.67)	0.50 (0.23, 1.11)
Safety from crime		
High	0.85 (0.47, 1.54)	0.35 (0.15, 0.80)*
Safety from traffic		
High	0.53 (0.30, 0.94)*	0.57 (0.29, 1.11)
Social environment		
High	0.82 (0.43, 1.55)	0.71 (0.30, 1.69)
Aesthetics		
High	0.69 (0.41, 1.16)	0.89 (0.45, 1.74)
Total perceived walkability	0.88 (0.76, 1.01)	0.76 (0.62, 0.93)*
Objective built environment		
Population density		
Within 800 m buffer	1.07 (0.72, 1.58)	0.73 (0.43, 1.24)
Within 1600 m buffer	1.16 (0.78, 1.72)	0.75 (0.44, 1.28)
Number of intersections		
Within 800 m buffer	0.97 (0.75, 1.26)	0.81 (0.59, 1.12)
Within 1600 m buffer	1.09 (0.84, 1.41)	0.84 (0.60, 1.18)
Availability of destinations		
Within 800 m buffer	1.19 (0.97, 1.47)	0.95 (0.66, 1.36)
Within 1600 m buffer	1.27 (0.99, 1.64)	0.97 (0.69, 1.37)
Walk Score®	1.21 (0.88, 1.67)	0.90 (0.61, 1.31)

Note: OR = odds ratio; CI = confidence interval; All models adjusted for age, working status, educational attainment, marital status, living status, gross annual household income, length of neighbourhood residence, neighbourhood socioeconomic status, and locality.
*$p \leq 0.05$.

found that lower perceived neighbourhood crime was associated with lower depressive symptoms (Hernandez et al., 2015). Another study conducted in India found an association between perceived neighbourhood safety and lower odds of older adults' major depression (Muhammad et al., 2021). Perceived crime may also influence depression via pathways other than walking and physical activity. Witnessing or hearing about crime in the neighbourhood can elicit negative emotions and thoughts that may lead to developing depressive symptoms (McCoy et al., 2016). While this pathway is possible, it has yet to be confirmed in the Japanese context. Further studies using actual crime data are needed to confirm our findings. Moreover, safety from crime was assumed to be often a more critical factor for women than men in terms of physical activity (Valson and Kutty, 2018). However, a higher proportion of women than men in our sample perceived their neighbourhood as safe from crime. The safety from crime question in our study, while referring to crime rates, also mentions walking. Since walking in middle-aged Japanese women tends to be higher than in middle-aged men (Inoue et al., 2010), our sample's different estimates of safety from crime across gender may reflect differences in walking behaviour. Future studies are needed to identify other contextual reasons, such as types of crime and media portrayal of crime, for the observed gender difference in safety from crime.

In contrast with perceived built environment measures, our study found no significant associations between objective built environment attributes and depressive symptoms. However, perceived measures of crime and traffic associated with depression in this study are not explicitly captured by the objective measures. Perceived walkability measures also do not necessarily reflect objective measures. The mismatch between objective and perceived built environment attributes has been shown in several previous studies conducted in different cultural contexts (Hoehner et al., 2005; Roda et al., 2016). Additionally, the depression measure in this study was based on the past week. However, depressive symptoms can be transient and can be triggered by events (US Department of Health Human Services, 2021). The objective built environment attributes, which are often stable in the long term, may impact the chronic state of depression. Furthermore, although several key objective built environment attributes were included in this study, we did not have parks and greenspace measures. Several previous studies have shown the positive effects of access to parks and green spaces on depressive symptoms (Asri et al., 2021; Gariepy et al., 2014; Liu et al., 2019; Mukherjee et al., 2017).

This study has some limitations. Since this is a secondary analysis of cross-sectional data, we could not draw causal relationships between variables. Notably, we cannot elaborate on the reverse causality for which depression could cause people to negatively perceive their neighbourhoods. The relatively low response rate (14.4 %) is also one of the limitations of this study. This may introduce a selection bias and lower the representativeness of the sample. The depression measure was self-reported in this study, which may be subject to recall bias. Additionally, it was impractical (i.e., unavailable, lack accuracy, and outdated) to use objective data for several measures such as crime, traffic, and parks in our study. Comparing perceived and objective built

environment attributes concerning depressive symptoms can offer the field several merits. For example, it can answer a fundamental question of whether urban design interventions to alleviate depressive symptoms should target residents' perceptions, places, or both. Future research with comparable perceived and objective measures of the built environment is necessary to shed light on this topic. This study focused on the residential neighbourhoods around participants' homes. For middle-aged adults aged 40–64 years, it is also likely that they could spend a considerable amount of their awake time at the workplace rather than at home. Variables such as time-based activity or detailed work-related variables (which were unavailable in this study) can be controlled to achieve more polished results. Future studies could also explore how workplace neighbourhoods may influence middle-aged adults' depressive symptoms. Nevertheless, residential neighbourhoods remain an essential spatial setting for adult residents' behaviours (Chum et al., 2019; Hillsdon et al., 2015). The strengths of this study were the use of both perceived and objective measures of the built environment and the focus on the less-studied age group of middle-aged adults.

6. Conclusions

Built environment design may influence depressive symptoms through several behavioural and social pathways. Our findings provide empirical behavioural insights that improving perceptions of neighbourhood walkability and, in particular, enhancing access to public transport and safety from crime and traffic are important for improving depressive symptoms in middle-aged men and women. This might be addressed through urban design interventions that reduce actual crime and traffic. Additional longitudinal studies addressing the reverse causality issue are necessary to examine the effect of the built environment design on depressive symptoms.

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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. In particular, none of the authors has a financial interest in https://www.walkscore.com/.

Data availability

Data will be made available on request.

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