Landscape and Urban Planning 214 (2021) 104184

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Traditional and novel walkable built environment metrics and social capital

Mohammad Javad Koohsari [a,b,c,*], Tomoki Nakaya [d], Gavin R. McCormack [a,e,f,g], Ai Shibata [h], Kaori Ishii [a], Akitomo Yasunaga [i], Tomoya Hanibuchi [d], Koichiro Oka [a]

[a] Faculty of Sport Sciences, Waseda University, Japan
[b] Behavioural Epidemiology Laboratory, Baker Heart and Diabetes Institute, Australia
[c] Melbourne School of Population and Global Health, The University of Melbourne, Australia
[d] Graduate School of Environmental Studies, Tohoku University, Japan
[e] Department of Community Health Sciences, Cumming School of Medicine, University of Calgary, Canada
[f] Faculty of Kinesiology, University of Calgary, Canada
[g] School of Architecture, Planning and Landscape, University of Calgary, Canada
[h] Faculty of Health and Sport Sciences, University of Tsukuba, Japan
[i] Faculty of Liberal Arts and Sciences, Bunka Gakuen University, Japan

HIGHLIGHTS

- Objective walkability was associated with lower activities with neighbors.
- Space syntax walkability was negatively associated with social capital scores.
- Walkable built environment may not necessarily be supportive of social capital.

ARTICLE INFO

Keywords:
Urban design
Social capital
Walkability
Neighborhood
Urban form
Social sustainability

ABSTRACT

A rapidly growing body of literature has explored associations between urban design attributes, which are conducive to walking, and social capital. The current study aimed to build on the limitations of previous research. Specifically, this study estimated the associations between traditional and novel walkable built environment metrics and social capital among a sample of adults in Japan. Data (n = 1010) from a randomly selected cross-section of residents (40–69 years old) from two areas in Japan were included. Social capital was assessed by questionnaires. Several objective and perceived walkable built environment attributes were calculated. Covariate-adjusted multivariable linear regression models were used to estimate associations between neighborhood built attributes and the three social capital scores. Street connectivity was negatively associated with activities with neighbors (b = -0.21, 95% CI -0.31, -0.11). Perceived population density was negatively associated with all three social capital scores, including social cohesion, activities with neighbors, and social participation (b = -0.21, 95% CI -0.30, -0.11, b = -0.15, 95% CI -0.24, -0.06, and b = -0.16, 95% CI -0.29, -0.02, respectively). Traditional walkability and Walk Score® were negatively associated with activities with neighbors (b = -0.04, 95% CI -0.07, -0.00 and b = -0.09, 95% CI -0.15, -0.04, respectively). No significant associations were observed between perceived walkability and social capital scores. Space syntax walkability was negatively associated with social cohesion and activities with neighbors (b = -0.12, 95% CI -0.23, -0.01 and b = -0.11, 95% CI -0.21, -0.01, respectively). This study provided unique findings demonstrating that walkable built environments may not necessarily support social capital in ultrahigh-density Asian cities.

1. Introduction

This study aims to investigate the links between the built environment and social capital. Social capital is defined as “the material, informational and affective resources to which individuals and potentially groups have access through social connections” (Moore et al.,

* Corresponding author at: 2-579-15 Mikajima, Tokorozawa, Saitama 359-1192, Japan.
E-mail addresses: mkoohsari@unimelb.edu.au (M.J. Koohsari), tomoki.nakaya.c8@tohoku.ac.jp (T. Nakaya), Gavin.McCormack@ucalgary.ca (G.R. McCormack), Shibata.ai.ga@u.tsukuba.ac.jp (A. Shibata), ishiikaori@waseda.jp (K. Ishii), yasunaga@bunka.ac.jp (A. Yasunaga), koka@waseda.jp (K. Oka).

https://doi.org/10.1016/j.landurbplan.2021.104184
Received 21 January 2021; Received in revised form 24 June 2021; Accepted 26 June 2021
Available online 13 July 2021

2009). Social capital also reflects “bonds between individuals”, which help them achieve their goals (Kunitz, 2004). There has been mounting evidence on the benefits of social capital on population health and well-being (Ehsan et al., 2019; McPherson et al., 2014; Nyqvist et al., 2013; Rodgers et al., 2019). For instance, an updated review of the literature provided evidence on the positive associations between social capital and self-rated health (Rodgers et al., 2019). An umbrella review of 20 systematic reviews found that social capital was linked to better mental and physical health and was protective against mortality (Ehsan et al., 2019). Social capital differs by sociodemographic factors, such as gender, income, education, and religion (Christoforou, 2011; Kaasa, 2013). Social capital can be perceived at the individual level but at a neighborhood level, can be operationalized as a compositional variable (e.g., the average social capital across people from the same neighborhood) (Perkins and Long, 2002).

The built environment has been identified as a contextual correlate of social capital (Eicher and Kawachi, 2011; Kawachi et al., 1999). The built environment is described as “the human-made space in which people live, work, and recreate on a day-to-day basis and it includes the buildings and spaces we create or modify” (Roof and Oleru, 2008). The pathways through which the built environment may influence social capital have yet to be completely elucidated. One potential hypothesis is that the observed associations between the built environment and social capital may be mediated by sedentary and physically active behaviors (Knudsen and Clark, 2013; Leyden, 2003). Research suggests there are links between higher physical activity and higher social capital (Di Bartolomeo and Papa, 2019; Ross and Searle, 2019; Werneck et al., 2019). Several systematic and narrative reviews have also provided evidence on the associations between built environment attributes and sedentary and physically active behaviors (Kärmeniemi et al., 2018; Koohsari et al., 2015b; McCormack and Shiell, 2011; O’donoghue et al., 2016). For instance, a systematic review found that those who lived in urban areas had lower levels of sedentary behavior than residents in regional (or rural) areas (Koohsari et al., 2015b). Another systematic review found that better availability of different types of destinations, public transportation, and mixed land uses was associated with greater physical activity (Kärmeniemi et al., 2018). The premise that a walkable built environment may foster social capital is also one of the key principles of the urban design movement of New Urbanism (Cabrera, 2013; Sander, 2002; Talen, 1999). As Talen (1999) states, “the essence of New Urbanism design theory is the creation of a sense of community.” The sense of community is an individual-level variable (perceived) that might reflect social capital (a contextual variable) (Perkins and Long, 2002). Neighborhoods built according to New Urbanism walkable design principles such as mixed land use, well-connected street layouts, and high density are assumed to promote social capital and increase a sense of community among residents.

Indeed, a rapidly growing body of literature has explored associations between built environment attributes, which are conducive to walking, and social capital (Du Toit et al., 2007; Hanibuchi et al., 2012; Mouratidis and Poortinga, 2020; Rogers and Sukolratanametee, 2009; Rogers et al., 2012; Toohey et al., 2013; Wood et al., 2010). Table 1 shows the characteristics of the previous key studies on this topic. For example, Rogers et al. (2012), using a participatory comparative case study approach, examined associations between perceived neighborhood walkability and social capital in two municipalities in New Hampshire, USA. They calculated perceived neighborhood walkability using the survey questions about where participants ‘can’ and ‘do’ walk in their community. They found that higher perceived walkability was positively associated with two social capital items of participation in community activities and trust index.

Nevertheless, this area of research has been limited in several important ways. First, most of the previous studies have considered either objective or perceived measures of the built environment in relation to social capital. Since there is a disagreement between objective and perceived built environment measures, they may have different effects on people’s behavior and health outcomes (Ball et al., 2008; Gebel et al., 2011; Koohsari et al., 2015a). A systematic review of 85

Table 1
Characteristics of the previous key studies on this topic.

Authors (Year)	Study location	Sample	Built environment attributes	Social capital items	Covariates
(Du Toit et al., 2007)	Adelaide, Australia	Adults	Neighborhood walkability index (dwelling density, street connectivity, and net retail area)	Sense of community, informal social control, social cohesion, and local social interaction	Age, gender, education, household income, number of children, household tenure and length of residency.
(Hanibuchi et al., 2012)	Chita Peninsula region, Japan	Older adults	Neighborhood walkability index (residential density, street connectivity, land use mix, and availability of parks)	General trust, norms of reciprocity, attachment to place, horizontal and vertical organization, and meeting friends	Age, gender, marital status, educational attainment, income, having paid work, and self-reported health
(Leyden, 2003)	Galway, Republic of Ireland	Household residents	Perceived neighborhood walkability	Know neighbors, political participation, trust, and social index	Age, child in home, watch TV, attend religious services, years in neighborhood, education, and party strength
(Mouratidis and Poortinga, 2020)	Oslo metropolitan area, Norway	Residents	Distance to city center, neighborhood density, local amenities, public transport, and green space	Social cohesion, urban vitality	Gender, age, cohabitation status, citizenship, education, household income, employmentstatus, presence of children, and time living in dwelling
(Rogers and Sukolratanametee, 2009)	Four neighborhoods from the Houston, Texas, metropolitan area	Residents	Neighborhood design (well-defined, mixed use, density, pedestrian friendly, public space)	Supportive acts of neighboring, neighbor annoyance, and neighborhood attachment and social ties	Years in neighborhood, number of children, full-time homemaker, and work within community
(Rogers et al., 2012)	Two municipalities in the state of New Hampshire, USA	Residents	Perceived neighborhood walkability	Trust index	Education, religious attendance, and years lived in current location
(Toohey et al., 2013)	Calgary, Canada	Adults $\geq$ 50 years	Street layout, green space, and population density	Sense of community	Self-reported health, dwelling type, neighborhood tenure, age, gender, marital status, household income, and education
(Wood et al., 2010)	Metropolitan Atlanta, USA	Household residents	Land use mix, street connectivity, commercial floor area ratio, residential density, and perceived neighborhood walkability	Sense of community	Gender, race, income, education, children under 18 years living at home, home ownership, and years lived in suburb

articles found that there was a low agreement between objective and perceived built environment measures, and that these measures had distinctive effects on physical activity (Orstad et al., 2017). Similarly, it is likely that associations between the built environment and social capital will differ depending on whether the built environment is objectively measured or self-reported.

Second, built environment attributes that support utilitarian or recreational walking coexist and interact with each other in neighborhoods (Koohsari et al., 2020a). For example, dense neighborhoods may be more likely to attract commercial destinations or have well-connected movement networks. It is important to understand the role of individual built environment attributes in supporting social capital because modifying a single attribute may be more feasible, especially in existing "built-out" neighborhoods. However, individual built environment attributes rarely influence physical activity or social capital in isolation; therefore, composite measures of the built environment should also be investigated. Notably, few studies have examined both individual and composite walkable built environment attributes and their associations with social capital (Jun and Hur, 2015; Kwon et al., 2017). One such composite built environment measure is the Walk Score®. The Walk Score® is a freely available composite walkability index that is easily accessible to a wide range of stakeholders without the need for data collection, calculation, or special training (Hall & Ram, 2018). Studies have found moderate to high correlations between the Walk Score® and other measures of walkability (Duncan, Aldstadt, Whalen, Melly, & Gortmaker, 2011; Koohsari et al., 2018b; Nykiforuk, McGetrick, Crick, & Johnson, 2016). While applying the Walk Score® can facilitate translating research findings on this topic into urban design and landscape practice, to the best of our knowledge, only one study has tested associations between the Walk Score® and social capital scores (Kwon et al., 2017). Kwon et al. (2017) found a positive association between the Walk Score® and community currency, one of the forms of social capital.

Third, few studies have explored associations between walkable built environments and social capital in different geographical contexts. Notably, there is a lack of studies conducted in the context of Asian countries. In their review, Mazumdar et al. (2018) found that only one out of 23 articles investigated the relationship between the built environment and social capital in the Asian context. Since Asian societies have unique built form characteristics (e.g., high density, compact form, and good public transport accessibility) and cultural attitudes (Koohsari et al., 2018a; Shelton, 2012), the findings of previous studies on the built environment and social capital conducted in Western countries may not be generalizable to Asian contexts. More region-specific evidence is needed to guide local urban design and landscape policies in (re) designing the built environment to foster social capital.

Finally, the role of space syntax walkability, a newly developed metric of the walkable built environment, has yet to be examined in relation to social capital. The details of the space syntax walkability index have been fully described elsewhere (Koohsari et al., 2016). Briefly, space syntax walkability consists of population density and space syntax measure of street integration (an indicator of movement network connectivity). A traditional walkability index usually requires parcel-level data on land uses and retail lands (Frank et al., 2010). Such data are either unavailable or expensive to access in several regions (Lotfi and Koohsari, 2011; Salvo et al., 2014). However, space syntax walkability can be calculated using readily available spatial data, including population density and street centrelines, and it can be estimated for different geographical contexts. This less data-dependent walkability index will provide a unique opportunity to extend the walkability research in areas where sourcing detailed spatial data is a challenge (Koohsari et al., 2019). Thus far, several studies have explored whether space syntax walkability is associated with sedentary and physically active behaviors, and health outcomes (Koohsari et al., 2020b; McCormack et al., 2019; Nichani et al., 2020). However, it remains unknown whether the space syntax walkability index is associated with social capital. Such evidence could provide urban designers and landscape architects with knowledge on novel but intuitive policy-relevant built environment indices in relation to social capital.

In summary, there are several gaps in the literature that this study aims to address: (a) there is a lack of studies that analysed both objective and perceived measures of the built environment in relation to social capital; (b) associations of individual and composite measures of the walkable environment with social capital were rarely explored together in one study; (c) there is a dearth of studies from Asia exploring these relationships; (d) the effects of space syntax walkability, a newly developed metric of the walkable built environment, on social capital is unknown. Therefore, the research questions of the current study are as follows: (1) what are the associations between perceived and objective walkable environment measures with social capital?; (2) how are individual and composite measures of walkable built environment linked to social capital?; (3) whether the observed associations between the walkable built environment and social capital differ in the context of Asia?; and (4) what is the association of space syntax walkability index with social capital?

2. Methods

2.1. Data source and participants

Cross-sectional data from the Healthy Built Environment in Japan (HEBEJ) project were used in this study. The HEBEJ was an observational investigation of how the built environment may support health behaviors and outcomes among middle- to older-aged adults in Japan. The study design and detailed methodology have been described elsewhere (Ishii et al., 2013). Briefly, data from a cross-section of residents (40–69 years old) randomly selected from the registry of residential addresses of two areas, Nerima Ward (n = 569) and Kanuma City (n = 507) in Japan, were included (n = 1,076, response rate = 35.9%) (Fig. 1). The Nerima Ward is one of the 23 Special Wards of Tokyo and is a typical case of a highly-populated residential district within a metropolitan area (721,722 persons in 2015). Kanuma City in Tochigi Prefecture is an example of a Japanese middle-sized regional city (98,374 persons in 2015). Fig. 2 shows the location of these two areas in Japan.

This sample selection process from an urban and a regional city was guided by the method of the International Physical Activity and the Environment Network (IPEN) studies in which participants were recruited from low and high walkable areas (Kerr et al., 2013). This sampling procedure ensures sufficient variability in the built environment exposures (Giles-Corti et al., 2005). For instance, the population density of the participants living in the Nerima Ward was 16,053 residents per km^2, while it was 2,081 residents per km^2 for those living in the Kanuma Ward. Participants' (one adult per household) sociodemographic, social capital, and health-related characteristics were obtained by a postal survey (from February through March 2011). The Institutional Ethics Committee of Waseda University approved this study (2010–238).

2.2. Measures

Social capital. Three social capital scores, including social cohesion, activities with neighbors, and social participation, were measured in this study. Social cohesion and activities with neighbors were assessed by asking participants about their level of agreement (1 = strongly agree to 5 = strongly disagree) with nine validated items (Mujahid et al., 2007). Social participation was defined as participants' involvement in six social activities (Ejiri et al., 2019; Levasseur et al., 2010). Table 2 presents the social capital scores and the question items used in this study.

The means of participants' four and five items were calculated as social cohesion and activities with neighbors scores, respectively. The response categories were reverse coded so that higher scores indicated higher social cohesion and activities with neighbors. The Cronbach's alpha of original social cohesion and activities with neighbors items

Fig. 1. Recruitment and selection process.

were 0.74 and 0.78, respectively (Mujahid et al., 2007). In our sample, the internal consistencies were adequate, with a Cronbach's alpha of 0.85 for both items. The total number of social activities ranging from 0 to 6 was assigned as the social participation score.

Individual walkable built environment attributes. Several objective and perceived individual walkable built environment attributes, including population density, availability of destinations, and street connectivity, were included in this study. Several studies have shown that these built attributes may support adults' active behaviors (Koohsari et al., 2017; Liao et al., 2018; McCormack et al., 2019). Objective built attributes were calculated by using geographic information systems (GIS) software. An 800 m (half a mile) circular buffer around participants' geocoded residential addresses was used to calculate neighborhood built attributes. This buffer size was similar to several previous studies that examined associations between the built environment and middle-to-older adults' health behaviours and outcomes (Nagel et al., 2008; Troped et al., 2014). The assumption is that most middle-to-older aged adults are able to walk within such a distance (which is about the distance that could be walked within 5–10 min) from their homes. GIS-derived built attributes were estimated using 2011 Environmental Systems Research Institute (ESRI) Japan data. To enable comparison across variables, each objective built environment attribute (population density, availability of destinations, and street connectivity) was standardized (i.e., z-scores).

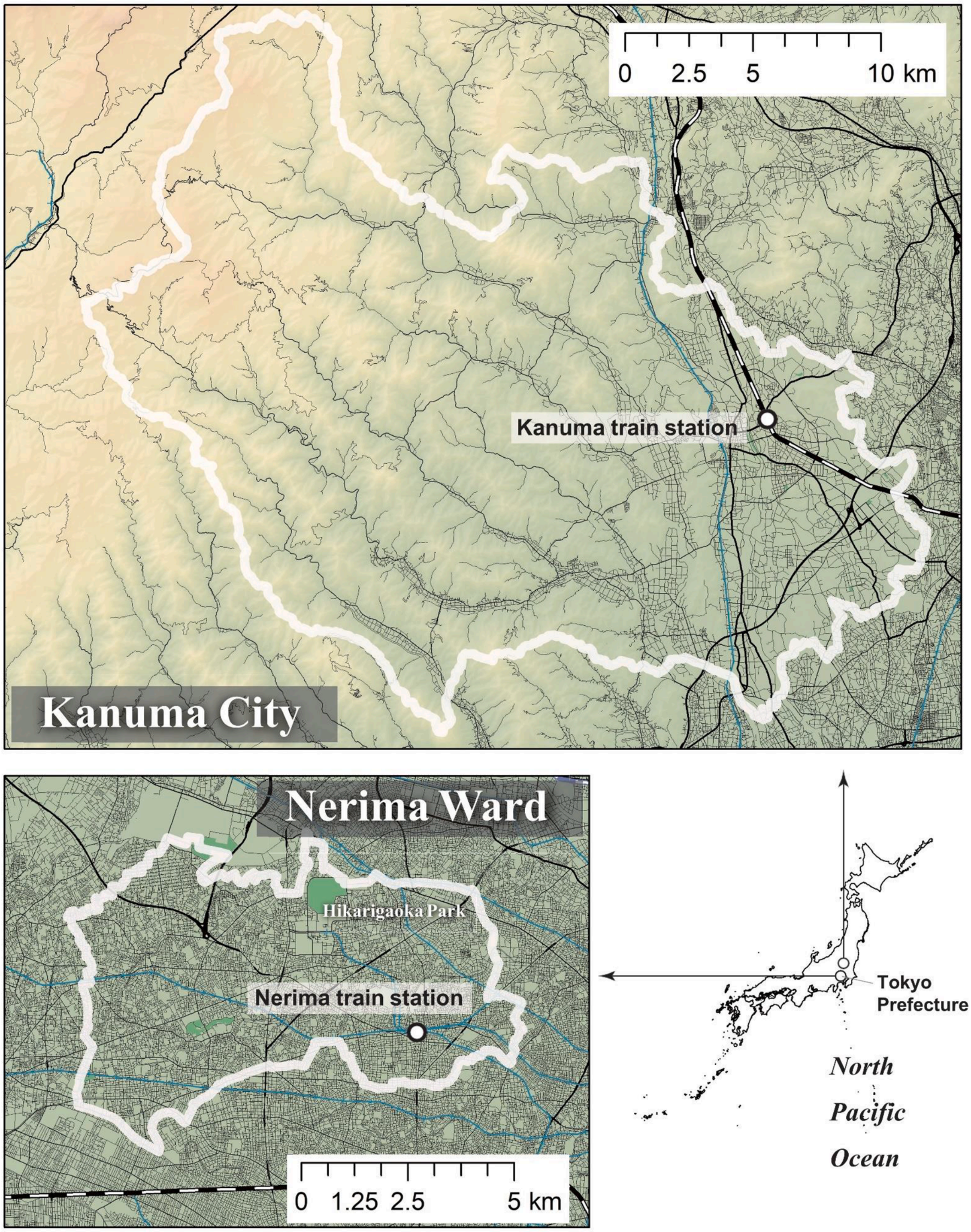

Fig. 2. The locations of Nerima Ward and Kanuma City in Japan.

The perceived walkable built attributes were assessed using the Japanese translated version of the International Physical Activity Questionnaire Environmental Module with a 4-point Likert scale (strongly agree, somewhat agree, somewhat disagree and strongly disagree). This questionnaire has been shown to have good test–retest reliability (kappa ranging from 0.63 to 0.97) (Inoue et al., 2009). Three items of the International Physical Activity Questionnaire Environmental Module were included: (1) perceived population density ("What is the main type of housing in your neighborhood?" For this question, the five answers 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); (2) perceived availability of destinations ("There are many places to go within easy walking distance of my home"); and (3) perceived street connectivity ("There are many 4-way intersections in my neighborhood"). Perceived population density was divided into "lower" (detached single-family housing) and "higher" (others). The other two perceived built attributes were categorized as "high" (strongly agree and somewhat agree) and "low" (somewhat disagree and strongly disagree).

Composite walkable built environment indices. Four composite objective and perceived indices of neighborhood walkability, including perceived walkability, traditional walkability, Walk Score®, and space

Table 2
Social capital scores included in this study.

	Question Items
Social cohesion (Mujahid et al., 2007)	1- People around here are willing to help their neighbors.2- People in my neighborhood generally get along with each other.3- People in my neighborhood can be trusted.4- People in my neighborhood share the same values.
Activities with neighbors (Mujahid et al., 2007)	1- About how often do you and people in your neighborhood do favors for each other? By favors, we mean such things as watching each other's children, helping with shopping, lending garden or house tools, and other small acts of kindness.2- When a neighbor is not at home or on vacation, how often do you and other neighbors watch over their property?3- How often do you and other people in the neighborhood ask each other for advice about personal things such as child-rearing or job openings?4- How often do you and people in your neighborhood have parties or other get togethers where other people in the neighborhood are invited?5- How often do you and other people in your neighborhood visit in each other's homes or speak with each other on the street?
Social participation (Ejiri et al., 2019; Levasseur et al., 2010)	Are you currently involved in any of these social activities (yes/no) - volunteer groups - civic/consumer movement groups - sports-related clubs - hobby and culture clubs - elderly, women, community clubs - others

syntax walkability, were included in this study. In line with several previous studies (Arvidsson et al., 2012; Orstad et al., 2018), perceived walkability was measured by summing the three perceived built attributes of perceived population density, perceived availability of destination, and perceived street connectivity, resulting in a possible range from 3 to 6. Similar to other studies (Christiansen et al., 2014; Eriksson et al., 2012), traditional walkability was calculated as the sum of the z-scores of population density, availability of destinations, and street connectivity. Walk Score®, a freely available index, was obtained from its website (www.walkscore.com). The concurrent validity of the Walk Score® in the Japanese context has been reported in detail elsewhere (Koohsari et al., 2018b). Koohsari et al. (2018b) found significant positive correlations between Walk Score® and objective measures of the walkable built environment, including population density, intersection density, local destinations, sidewalk availability, and access to public transportation. In brief, significant positive associations were found between Walk Score® and objectively measured walkable built environment attributes in Japan (Koohsari et al., 2018b). Walk Scores® were extracted by entering each participant's residential home address into the Walk Score® publicly available website (www.walkscore.com) by two independent project members. The first author checked the agreement between the Walk Score® values obtained by the two members.

Space syntax walkability was calculated for each participant using the following formula (Koohsari et al., 2016): Space syntax walkability $= Z$ [(Z population density) $+ 2\times$(Z street integration)]. Street integration, a key space syntax measure, indicates how "topologically" a street segment is located within a network (Klarqvist, 1993). A street segment with higher integration values requires fewer turns to be reached compared with one with lower integration scores. Fig. 3 illustrates (a) a neighborhood block schematic, (b) its axial lines, and (c) the level of street integration. Axial lines are the basis of space syntax measure of integration and it is considered as lines of sight in urban environments (Liu and Jiang, 2012). Using Axwoman (Jiang, 2012) and University College London DepthMap (Turner, 2004), an integration value was calculated for each street segment.

Sociodemographic covariates. Participants reported the following sociodemographic variables: age, gender (female, male), marital status (single, married), educational attainment (tertiary or higher, below tertiary), employment status (employed, unemployed), living status (alone, with others), and household income (<¥5,000,000, ≥¥5,000,000). Furthermore, a dichotomous area variable (Nerima Ward, Kanuma City) was included as a covariate representing locality effects at the city level.

2.3. Statistical analysis

Descriptive statistics, including frequencies and measures of central tendency and variation, were estimated for sociodemographic and participants' neighborhood built attributes. Pearson's correlation coefficient was used to test the correlations between social capital scores, and between built environment indices. Covariate-adjusted multivariable linear regression models were used to estimate associations between neighborhood built attributes and the three social capital scores. For all point estimates (b = unstandardized regression coefficients), 95% confidence intervals (CIs) were estimated. Those sociodemographic variables that were found to be statistically related were included as covariates in the models. Since multicollinearity was detected for all neighborhood built attributes in the model — the variance inflation factor > 5 (O'Brien, 2007) —, each perceived and objective neighborhood built attribute was included separately in the models to avoid collinearity problems. Normality assumptions were checked by the QQ plots of the residuals. Multilevel models were not used because intra-area clustering was small and not statistically significant. A complete-

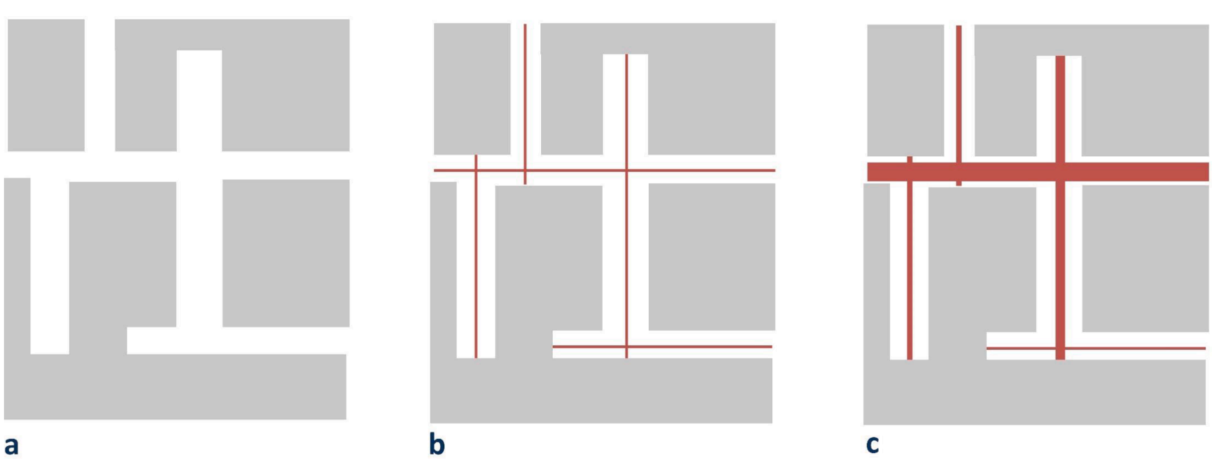

Fig. 3. (a) a neighborhood, (b) its axial lines, and (c) street integration (thicker lines show higher street integration).

case analysis was chosen because the proportion of missing data for our variables of interest was low (5%) (Jakobsen et al., 2017). Analyses were conducted using Stata 15.0 (Stata Corp, College Station, Texas), and the level of significance was set at $p < 0.05$.

3. Results

After excluding those with missing data (n = 66), complete data from 1,010 participants were included in this analysis. Table 3 shows the study sample's characteristics. Our sample consisted of mostly males (52.2%), couples (85.1%), tertiary or higher educated individuals (53.6%), employed individuals (74.1%), those living with others (93.1%), and those with a household income of five million yen (equivalent to about US$47,000) or more (50.8%), with a mean age of 55.4 ± 8.4 years. The average scores of social cohesion, activities with neighbors, and social participation were 3.3 (out of five), 1.9 (out of five), and 0.9 (out of six), respectively (higher scores mean better social cohesion, activities with neighbors, and social participation). There were significant ($p < 0.05$) Pearson's correlations between social cohesion and activities with neighbors ($r = 0.59$), social cohesion and social participation ($r = 0.20$), and activities with neighbors and social participation ($r = 0.30$). Among the built environment indices, there were significant Pearson's correlations between perceived walkability and traditional walkability ($r = 0.66$), perceived walkability and Walk Scores® ($r = 0.73$), perceived walkability and space syntax walkability ($r = 0.57$), traditional walkability and Walk Scores® ($r = 0.83$), traditional walkability and space syntax walkability ($r = 0.88$), and Walk Scores® and space syntax walkability ($r = 0.73$). Table 4 shows the mean scores for participants' neighborhood built environment attributes.

Table 3
Characteristics of study participants (N = 1,010).

Variable	Mean (SD) or N (%)		
	Total	Nerima Ward (N = 540)	Kanuma City (N = 470)
Age (years)	55.4 (8.4)	55.7 (8.5)	55.0 (8.2)
Gender			
Female	483 (47.8)	263 (48.7)	220 (46.8)
Male	527 (52.2)	277 (51.3)	250 (53.2)
Marital status			
Single	150 (14.9)	85 (15.7)	65 (13.8)
Couple	860 (85.1)	455 (84.3)	405 (86.2)
Educational attainment			
Tertiary or higher	541 (53.6)	369 (68.3)	172 (36.6)
Below tertiary	469 (46.4)	171 (31.7)	298 (63.4)
Employment status			
Employed	748 (74.1)	397 (73.5)	351 (74.7)
Unemployed	262 (25.9)	143 (26.5)	119 (25.3)
Living status			
Alone	70 (6.9)	47 (8.7)	23 (4.9)
With others	940 (93.1)	493 (91.3)	447 (95.1)
Household income (per annum)			
< ¥5,000,000 [a]	497 (49.2)	242 (44.8)	255 (54.3)
≥¥5,000,000 [a]	513 (50.8)	298 (55.2)	215 (45.7)
Social cohesion	3.3 (0.7)	3.2 (0.7)	3.4 (0.7)
Activities with neighbors	1.9 (0.6)	1.8 (0.6)	2.1 (0.6)
Social participation	0.9 (1.0)	0.8 (0.9)	1.0 (1.0)

[a]¥5,000,000 is equivalent to about US$47,000.

Table 4
Participants' neighborhood built environment attributes (N = 1,010).

Variable	Mean (SD) or N (%)		
	Total	Nerima Ward (N = 540)	Kanuma City (N = 470)
Population density[a]	9551.2 (8120.7)	16053.2 (5321.9)	2080.7 (2172.6)
Availability of destinations[b]	62.2 (52.4)	97.9 (43.4)	21.3 (24.6)
Street connectivity[c]	355.7 (230.8)	555.6 (80.9)	126.1 (90.8)
Perceived population density			
High	332 (32.9)	273 (50.6)	59 (12.6)
Low	678 (67.1)	267 (49.4)	411 (87.4)
Perceived availability of destinations			
High	622 (61.6)	462 (85.6)	160 (34.0)
Low	388 (38.4)	78 (14.4)	310 (66.0)
Perceived street connectivity			
High	713 (70.6)	446 (82.6)	267 (56.8)
Low	297 (29.4)	94 (17.4)	203 (43.2)
Traditional Walkability	-0.0 (2.8)	2.4 (1.3)	-2.7 (1.0)
Perceived walkability	4.7 (1.0)	5.2 (0.8)	4.0 (1.0)
Walk Score®	62.2 (27.6)	80.5 (8.8)	41.1 (26.9)
Space syntax walkability	-0.003 (1.0)	0.9 (0.5)	-1.0 (0.2)

[a]The number of residents per km^2; [b]the number of destinations per km^2; [c]the number of three-way or more intersections per square km^2.

Table 5 shows the results of the associations between walkable built environment attributes and social capital scores. Among objective individual measures, street connectivity was negatively associated with activities with neighbors (b = -0.21, 95% CI -0.31, -0.11). Among perceived individual measures, adjusting for covariates, perceived population density was negatively associated with all three social capital scores, including social cohesion, activities with neighbors, and social participation (b = -0.21, 95% CI -0.30, -0.11, b = -0.15, 95% CI -0.24, -0.06, and b = -0.16, 95% CI -0.29, -0.02, respectively). Traditional walkability and Walk Score® were negatively associated with activities with neighbors (b = -0.04, 95% CI -0.07, -0.00 and b = -0.09, 95% CI -0.15, -0.04, respectively). No significant associations were observed between perceived walkability and social capital scores. Space syntax walkability was negatively associated with social cohesion and activities with neighbors (b = -0.12, 95% CI -0.23, -0.01 and b = -0.11, 95% CI -0.21, -0.01, respectively).

4. Discussion

Walkable built environment attributes may foster social capital by providing residents with opportunities to be physically active and have social interactions within their neighborhoods (Du Toit et al., 2007; Leyden, 2003; Wood et al., 2010). However, research to date is limited in several key aspects, as previously described. Therefore, using data from Japan, this study analyzed associations between traditional and novel walkable built environment metrics and social capital.

4.1. Principal findings

We found that two walkable built environment attributes, street connectivity and perceived population density, were associated with lower social capital scores. These findings are consistent with several previous studies that reported that street connectivity or population density was inversely associated with social capital (Brueckner and Largey, 2008; Dempsey, 2008; French et al., 2014; Muzayanah et al., 2020; Nguyen, 2010). For example, a study conducted in the U.S. found that population density and street connectivity at the county level were

Table 5
Associations of walkable built environment attributes with social capital scores (N = 1,010).

	Social cohesion		Activities with neighbors		Social participation	
	b	(95% CI)	*b*	(95% CI)	*b*	(95% CI)
Individual neighborhood built environment attributes						
Population density	-0.07	(-0.15, 0.01)	-0.02	(-0.10, 0.05)	-0.06	(-0.18, 0.05)
Availability of destinations	0.02	(-0.04, 0.08)	-0.03	(-0.09, 0.02)	0.01	(-0.07, 0.10)
Street connectivity	-0.09	(-0.20, 0.02)	-0.21*	(-0.31, -0.11)	-0.01	(-0.17, 0.14)
Perceived population density						
High	-0.21*	(-0.30, -0.11)	-0.15*	(-0.24, -0.06)	-0.16*	(-0.29, -0.02)
Perceived availability of destinations						
High	0.08	(-0.01, 0.18)	0.04	(-0.05, 0.13)	0.03	(-0.11, 0.16)
Perceived street connectivity						
High	0.00	(-0.09, 0.10)	-0.04	(-0.13, 0.05)	0.12	(-0.01, 0.25)
Composite neighborhood built environment indices						
Traditional Walkability	-0.02	(-0.05, 0.02)	-0.04*	(-0.07, -0.00)	-0.01	(-0.06, 0.04)
Perceived walkability	-0.03	(-0.08, 0.02)	-0.04	(-0.08, 0.01)	-0.00	(-0.07, 0.06)
Walk Score®	-0.05	(-0.11, 0.01)	-0.09*	(-0.15, -0.04)	-0.02	(-0.10, 0.06)
Space syntax walkability	-0.12*	(-0.23, -0.01)	-0.11*	(-0.21, -0.01)	0.02	(-0.14, 0.17)

Note *b* = unstandardized regression coefficients; CI = confidence interval; population density, availability of destinations, and street connectivity were standardized (i.e., z-scores) prior to the regression analysis. All models were adjusted for age, gender, marital status, educational attainment, employment status, living status, household income, and locality. * $p < 0.05$.

negatively associated with social capital scores (Nguyen, 2010). In contrast, some studies have demonstrated positive effects of population density and street connectivity on social capital (Knudsen and Clark, 2013; Won and Lee, 2020). As discussed by French et al. (2014), residents in high-density areas may encounter many strangers daily and thus prefer to limit such interactions. Overcrowding is an issue in many Asian environments, and it is difficult to discern familiar faces in large populations. If there are many people around, then it is less likely that someone will see the same people and therefore there are fewer opportunities to develop meaningful conversations and relationships. If someone sees the same people day to day, they may feel inclined to begin a conversation. Additionally, while well-connected street layouts support active transport (Christian et al., 2017; Ozbil et al., 2011; Sarkar et al., 2015), safety from traffic can be a concern in such areas. For instance, Marshall and Garrick (2011) found that street connectivity was associated with an increase in collisions. Poor traffic safety may be a barrier for residents to get around their neighborhoods, and it can negatively affect social capital (French et al., 2014). There may also be optimal levels of population density above which the population density has adverse effects on social capital. For instance, the average population densities in Japanese cities are generally higher than those in Western environments (Koohsari et al., 2018a). Such high levels of population density may negatively affect social capital. Further research is needed to identify the optimal levels of population density and street connectivity supportive of social capital.

In line with previous studies (Jun and Hur, 2015; Mouratidis and Poortinga, 2020; Muzayanah et al., 2020), we found that several composite measures of the walkable built environment were adversely associated with social capital scores: more walkable neighborhoods tend to have lower social capital scores. The only previous study conducted in Japan also found nonsignificant or negative associations between neighborhood walkability and social capital scores (Hanibuchi et al., 2012). The exact reasons for the observed negative effects of neighborhood walkability on social capital have yet to be explored. As mentioned above, the extreme levels of built environment attributes in a Japanese environment may play a role in the observed negative associations between walkability and social capital. Additionally, there may be some unmeasured intermediate factors that are responsible for the adverse effects of walkability on social capital. For example, walkable areas are likely to host many commercial destinations, human and car movements, and consequently, air pollution and crime. These factors may be obstacles to instigating meaningful social interactions in these areas. Moreover, the amount of overall walking behavior in walkable neighborhoods may not be enough to initiate social interactions with neighbors and foster social capital in these areas. Furthermore, the type of walking (i.e., utilitarian walking, walking at work, recreational walking) may be an important factor for initiating social interactions. For example, walking dogs might facilitate conversations as owners and their dogs interact and therefore provide opportunities to form acquaintanceships and friendships (Christian et al., 2018; Wood et al., 2005). These findings are in contrast with the hypothesis that a walkable built environment can promote social capital (Kwon et al., 2017; Leyden, 2003; Rogers et al., 2012, 2013; Zhu et al., 2014). For instance, Kwon et al. (2017) found that neighborhood walkability (measured by Walk Score®) was positively associated with community currency, a form of social capital. Notably, some of these previous studies were conducted in small socially cohesive areas, as opposed to large cities and towns (Leyden, 2003; Rogers et al., 2012, 2013). There may be several reasons for the inconsistent findings on this topic. There is a lack of consensus in defining social capital in previous studies. Different built environment attributes were also applied to conceptualize walkable environments in studies on this topic. These may cause difficulties in comparing and collating evidence across different studies (Mazumdar et al., 2018).

We found that objective and perceived measures of the walkable built environment have distinctive effects on social capital. While objective street connectivity and perceived population density were unfavorably associated with social capital, no associations were observed for perceived street connectivity and objective population density. These findings are consistent with two previous studies that reported different associations of objective and perceived built environment measures with social capital (French et al., 2014; Jun and Hur, 2015). Objective and perceived measures of the built environment capture different aspects of an environment and do not always concur with each other (Ball et al., 2008; Gebel et al., 2011; Koohsari et al., 2015a). For instance, a study conducted in Australia found that>50% of participants misperceived higher street connectivity as being lower (Koohsari et al., 2015a). These findings highlight the importance of assessing both objective and perceived measures of the built environment in relation to social capital. Theoretically, perceptions of the built environment could be changed up to a point without changing the objective built environment. For instance, there is some evidence that providing people with maps can enhance their awareness and perceptions of their environment (De Cocker et al., 2007). This becomes particularly important when neighborhoods are built out, and not much can be done in the way of modifications — then perceptions might be targeted to foster social capital.

Our findings also suggest that a newly developed index of walkability, space syntax walkability, was negatively associated with social capital scores. To the best of our knowledge, no previous studies have assessed whether space syntax walkability is associated with social capital. It was therefore not possible to compare these findings with any previous studies. Higher space syntax walkability was found to be positively associated with utilitarian and recreational walking behaviors in several previous studies (Koohsari et al., 2016; McCormack et al., 2019). Thus, similar to our findings on traditional walkable built environment metrics, its negative association with social capital can be seen as an unexpected finding. Space syntax walkability can be calculated without the need for extensive spatial data since it only requires widely available data on population density and street centerlines (Koohsari et al., 2016). The space syntax method has also been applied by urban design and landscape practitioners for many years (Karimi, 2012). Therefore, space syntax walkability has an opportunity to provide a bridge in translating the findings on the built environment and social capital to urban design and landscape practice. Moreover, we found that Walk Score®, a freely-available walkability index, was adversely associated with a social capital score of activities with neighbors. There is a call for less data-dependent and more urban design policy-relevant built environment metrics in social and health-related research (Giles-Corti et al., 2015). Space syntax walkability and Walk Score® indices can provide easy-to-obtain and policy-relevant metrics of the built environment associated with social capital. Further research is needed to apply these indices in other geographical regions to confirm their utilities in relation to social capital scores.

4.2. Limitations and strengths

This study had some limitations. Since this is a cross-sectional study, causal relationships between the variables cannot be inferred. Future studies with longitudinal designs are needed to provide evidence for establishing temporality between walkable built environment attributes and social capital. Objective built environment measures were only available within one spatial buffer (800 m buffer) in this study (due to limited logistics at the time of spatial data linkage). However, one spatial buffer may not truly represent the built environment attributes to which participants were exposed. A circular buffer might also be capturing built attributes that are not reachable within 800 m via the street network. A variety of spatial buffers or activity spaces identified by global positioning system points can be applied to investigate built environment and social capital relations (Chaix et al., 2013; Kestens et al., 2018; Mavoa et al., 2019).

Walk Score® measure is also limited in several ways. Walk Score® does not include several important built environment features relevant to overall walking, such as slope, availability of sidewalks, attributes related to safety from traffic or crime, and subjective attributes such as aesthetics. The algorithm and procedure of calculating Walk Score® are also not (currently) fully open to the public as a commercial product. Furthermore, the data on the length of residence were unavailable in this study. Length of residence could act as a proxy measure for neighborhood exposure, and it may also be anticipated that those who have resided in a neighborhood for a certain amount of time have more chances to meet and connect with people. Collecting data from areas with diverse urban design attributes, applying novel metrics of the walkable built environment, analyzing both objective and perceived measures of the built environment, and focusing on the less-explored geographical context of the Asian environment are strengths of this study.

5. Conclusions

There are numerous calls to foster social capital as a means of supporting people's health and well-being. However, it is impossible or impractical to change many sociodemographic factors relevant to social capital. The built environment provides a modifiable opportunity to influence social capital through behavioral pathways such as walking and social interactions. The current study adds to the limited but rapidly growing literature on urban design, landscape, and public health that examines associations between the walkable built environment and social capital. By addressing several of the previous limitations, this study provides unique findings that a walkable built environment may not necessarily be supportive of social capital. Future research should build on the limitations of the present study to move this research agenda forward.

CRediT authorship contribution statement

Mohammad Javad Koohsari: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Tomoki Nakaya:** Methodology, Writing – review & editing. **Gavin R. McCormack:** Methodology, Writing – review & editing. **Ai Shibata:** Project administration, Writing – review & editing. **Kaori Ishii:** Project administration, Writing – review & editing. **Akitomo Yasunaga:** Methodology, Writing – review & editing. **Tomoya Hanibuchi:** Methodology, Writing – review & editing. **Koichiro Oka:** Conceptualization, Supervision, Writing – review & editing.

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 Walk Score.

Acknowledgments

Nakaya was supported by the JSPS KAKENHI (#20H00040). McCormack is supported by a Canadian Institutes of Health Research Foundations Scheme Grant (FDN-154331). Hanibuchi was supported by a Japan Society for the Promotion of Sciences (KAKENHI Grant 18KK0371 and 17H00947). Oka is supported by a Grant-in-Aid for Scientific Research (No. 20H04113) from the Japan Society for the Promotion of Science.

References

Arvidsson, D., Kawakami, N., Ohlsson, H., & Sundquist, K. (2012). Physical activity and concordance between objective and perceived walkability. *Medicine & Science in Sports & Exercise, 44*(2), 280–287.

Ball, K., Jeffery, R. W., Crawford, D. A., Roberts, R. J., Salmon, J., & Timperio, A. F. (2008). Mismatch between perceived and objective measures of physical activity environments. *Preventive Medicine, 47*(3), 294–298.

Brueckner, J. K., & Largey, A. G. (2008). Social interaction and urban sprawl. *Journal of Urban Economics, 64*(1), 18–34.

Cabrera, J. F. (2013). New urbanism and selection bias in the formation of social capital. *Housing Policy Debate, 23*(2), 376–394.

Chaix, B., Meline, J., Duncan, S., Merrien, C., Karusisi, N., Perchoux, C., … Kestens, Y. (2013). GPS tracking in neighborhood and health studies: A step forward for environmental exposure assessment, a step backward for causal inference? *Health & Place, 21*, 46–51.

Christian, H., Bauman, A., Epping, J. N., Levine, G. N., McCormack, G., Rhodes, R. E., … Westgarth, C. (2018). Encouraging dog walking for health promotion and disease prevention. *American Journal of Lifestyle Medicine, 12*(3), 233–243.

Christian, H., Knuiman, M., Divitini, M., Foster, S., Hooper, P., Boruff, B., … Giles-Corti, B. (2017). A longitudinal analysis of the influence of the neighborhood environment on recreational walking within the neighborhood: Results from RESIDE. *Environmental Health Perspectives, 125*(7), Article 077009.

Christiansen, L. B., Toftager, M., Schipperijn, J., Ersbøll, A. K., Giles-Corti, B., & Troelsen, J. (2014). School site walkability and active school transport–association, mediation and moderation. *Journal of Transport Geography, 34*, 7–15.

Christoforou, A. (2011). Social capital across European countries: Individual and aggregate determinants of group membership. *American Journal of Economics and Sociology, 70*(3), 699–728.

De Cocker, K. A., De Bourdeaudhuij, I. M., Brown, W. J., & Cardon, G. M. (2007). Effects of "10,000 steps Ghent": A whole-community intervention. *American Journal of Preventive Medicine, 33*(6), 455–463.

Dempsey, N., 2008, Does quality of the built environment affect social cohesion?, Proceedings of the Institution of Civil Engineers-Urban Design and Planning 161(3): 105-114.
Di Bartolomeo, G., & Papa, S. (2019). The effects of physical activity on social interactions: The case of trust and trustworthiness. *Journal of Sports Economics, 20* (1), 50–71.
Du Toit, L., Cerin, E., Leslie, E., & Owen, N. (2007). Does walking in the neighbourhood enhance local sociability? *Urban Studies, 44*(9), 1677–1695.
Duncan, D. T., Aldstadt, J., Whalen, J., Melly, S. J., & Gortmaker, S. L. (2011). Validation of Walk Score® for estimating neighborhood walkability: An analysis of four US metropolitan areas. *International Journal of Environmental Research and Public Health, 8*(11), 4160–4179.
Ehsan, A., Klaas, H. S., Bastianen, A., & Spini, D. (2019). Social capital and health: A systematic review of systematic reviews. *SSM-Population Health, 8*, Article 100425.
Eicher, C., Kawachi, I., 2011, Social capital and community design, in: Making healthy places, Springer, pp. 117-128.
Ejiri, M., Kawai, H., Fujiwara, Y., Ihara, K., Watanabe, Y., Hirano, H., … Obuchi, S. (2019). Social participation reduces isolation among Japanese older people in urban area: A 3-year longitudinal study. *PloS One, 14*(9), Article e0222887.
Eriksson, U., Arvidsson, D., Gebel, K., Ohlsson, H., & Sundquist, K. (2012). Walkability parameters, active transportation and objective physical activity: Moderating and mediating effects of motor vehicle ownership in a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity, 9*(1), 123.
Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). The development of a walkability index: Application to the Neighborhood Quality of Life Study. *British Journal of Sports Medicine, 44*(13), 924–933.
French, S., Wood, L., Foster, S. A., Giles-Corti, B., Frank, L., & Learnihan, V. (2014). Sense of community and its association with the neighborhood built environment. *Environment and Behavior, 46*(6), 677–697.
Gebel, K., Bauman, A. E., Sugiyama, T., & Owen, N. (2011). Mismatch between perceived and objectively assessed neighborhood walkability attributes: Prospective relationships with walking and weight gain. *Health & Place, 17*(2), 519–524.
Giles-Corti, B., Sallis, J. F., Sugiyama, T., Frank, L. D., Lowe, M., & Owen, N. (2015). Translating active living research into policy and practice: One important pathway to chronic disease prevention. *Journal of Public Health Policy, 36*(2), 231–243.
Giles-Corti, B., Timperio, A., Bull, F., & Pikora, T. (2005). Understanding physical activity environmental correlates: Increased specificity for ecological models. *Exercise and Sport Sciences Reviews, 33*(4), 175–181.
Hall, C. M., & Ram, Y. (2018). Walk score® and its potential contribution to the study of active transport and walkability: A critical and systematic review. *Transportation Research Part D: Transport and Environment, 61*, 310–324.
Hanibuchi, T., Kondo, K., Nakaya, T., Shirai, K., Hirai, H., & Kawachi, I. (2012). Does walkable mean sociable? Neighborhood determinants of social capital among older adults in Japan. *Health & Place, 18*(2), 229–239.
Inoue, S., Murase, N., Shimomitsu, T., Ohya, Y., Odagiri, Y., Takamiya, T., … Sallis, J. F. (2009). Association of physical activity and neighborhood environment among Japanese adults. *Preventive Medicine, 48*(4), 321–325.
Ishii, K., Shibata, A., & Oka, K. (2013). Sociodemographic and anthropometric factors associated with screen-based sedentary behavior among Japanese adults: A population-based cross-sectional study. *Journal of Epidemiology, 23*(5), 382–388.
Jakobsen, J. C., Gluud, C., Wetterslev, J., & Winkel, P. (2017). When and how should multiple imputation be used for handling missing data in randomised clinical trials–a practical guide with flowcharts. *BMC Medical Research Methodology, 17*(1), 162.
Jiang, B., 2012, Axwoman 6.0: An ArcGIS extension for urban morphological analysis, University of Gävle, Sweden.
Jun, H.-J., & Hur, M. (2015). The relationship between walkability and neighborhood social environment: The importance of physical and perceived walkability. *Applied Geography, 62*, 115–124.
Kaasa, A. (2013). Religion and social capital: Evidence from European countries. *International Review of Sociology, 23*(3), 578–596.
Karimi, K. (2012). A configurational approach to analytical urban design:'Space syntax'methodology. *Urban Design International, 17*(4), 297–318.
Kärmeniemi, M., Lankila, T., Ikäheimo, T., Koivumaa-Honkanen, H., & Korpelainen, R. (2018). The built environment as a determinant of physical activity: A systematic review of longitudinal studies and natural experiments. *Annals of Behavioral Medicine, 52*(3), 239–251.
Kawachi, I., Kennedy, B. P., & Glass, R. (1999). Social capital and self-rated health: A contextual analysis. *American Journal of Public Health, 89*(8), 1187–1193.
Kerr, J., Sallis, J. F., Owen, N., De Bourdeaudhuij, I., Cerin, E., Sugiyama, T., … Mitáš, J. (2013). Advancing science and policy through a coordinated international study of physical activity and built environments: IPEN adult methods. *Journal of Physical Activity and Health, 10*(4), 581–601.
Kestens, Y., Thierry, B., Shareck, M., Steinmetz-Wood, M., & Chaix, B. (2018). Integrating activity spaces in health research: Comparing the VERITAS activity space questionnaire with 7-day GPS tracking and prompted recall. *Spatial and Spatio-Temporal Epidemiology, 25*, 1–9.
Klarqvist, B. (1993). A space syntax glossary. *Nordisk Arkitekturforskning, 2*, 11–12.
Knudsen, B. B., & Clark, T. N. (2013). Walk and be moved: How walking builds social movements. *Urban Affairs Review, 49*(5), 627–651.
Koohsari, M. J., Badland, H., Sugiyama, T., Mavoa, S., Christian, H., & Giles-Corti, B. (2015a). Mismatch between perceived and objectively measured land use mix and street connectivity: Associations with neighborhood walking. *Journal of Urban Health, 92*(2), 242–252.
Koohsari, M. J., McCormack, G. R., Nakaya, T., & Oka, K. (2020a). Neighbourhood built environment and cardiovascular disease: Knowledge and future directions. *Nature Reviews Cardiology, 17*(5), 261–263.
Koohsari, M. J., Nakaya, T., & Oka, K. (2018a). Activity-Friendly built environments in a Super-Aged Society, Japan: Current challenges and toward a research agenda. *International Journal of Environmental Research and Public Health, 15*(9), 2054.
Koohsari, M. J., Oka, K., Nakaya, T., Shibata, A., Ishii, K., Yasunaga, A., & McCormack, G. R. (2020b). Environmental attributes and sedentary behaviours among Canadian adults. *Environmental Research Communications, 2*(5), Article 051002.
Koohsari, M. J., Oka, K., Owen, N., & Sugiyama, T. (2019). Natural movement: A space syntax theory linking urban form and function with walking for transport. *Health & place, 58*, Article 102072.
Koohsari, M. J., Owen, N., Cerin, E., Giles-Corti, B., & Sugiyama, T. (2016). Walkability and walking for transport: Characterizing the built environment using space syntax. *International Journal of Behavioral Nutrition and Physical Activity, 13*(1), 1–9.
Koohsari, M. J., Sugiyama, T., Hanibuchi, T., Shibata, A., Ishii, K., Liao, Y., & Oka, K. (2018b). Validity of Walk Score® as a measure of neighborhood walkability in Japan. *Preventive Medicine Reports, 9*, 114–117.
Koohsari, M. J., Sugiyama, T., Sahlqvist, S., Mavoa, S., Hadgraft, N., & Owen, N. (2015b). Neighborhood environmental attributes and adults' sedentary behaviors: Review and research agenda. *Preventive Medicine, 77*, 141–149.
Koohsari, M. J., Sugiyama, T., Shibata, A., Ishii, K., Liao, Y., Hanibuchi, T., … Oka, K. (2017). Associations of street layout with walking and sedentary behaviors in an urban and a rural area of Japan. *Health & Place, 45*, 64–69.
Kunitz, S. J. (2004). Social capital and health. *British Medical Bulletin, 69*(1), 61–73.
Kwon, M., Lee, C., & Xiao, Y. (2017). Exploring the role of neighborhood walkability on community currency activities: A case study of the crooked river alliance of TimeBanks. *Landscape and Urban Planning, 167*, 302–314.
Levasseur, M., Richard, L., Gauvin, L., & Raymond, É. (2010). Inventory and analysis of definitions of social participation found in the aging literature: Proposed taxonomy of social activities. *Social Science & Medicine, 71*(12), 2141–2149.
Leyden, K. M. (2003). Social capital and the built environment: The importance of walkable neighborhoods. *American Journal of Public Health, 93*(9), 1546–1551.
Liao, Y., Shibata, A., Ishii, K., Koohsari, M. J., Inoue, S., & Oka, K. (2018). Can neighborhood design support walking? Cross-sectional and prospective findings from Japan. *Journal of Transport & Health, 11*, 73–79.
Liu, X., & Jiang, B. (2012). Defining and generating axial lines from street center lines for better understanding of urban morphologies. *International Journal of Geographical Information Science, 26*(8), 1521–1532.
Lotfi, S., & Koohsari, M. J. (2011). Neighborhood walkability in a city within a developing country. *Journal of urban planning and development, 137*(4), 402–408.
Marshall, W. E., & Garrick, N. W. (2011). Does street network design affect traffic safety? *Accident Analysis & Prevention, 43*(3), 769–781.
Mavoa, S., Bagheri, N., Koohsari, M. J., Kaczynski, A. T., Lamb, K. E., Oka, K., O'sullivan, D., & Witten, K. (2019). How do neighbourhood definitions influence the associations between built environment and physical activity? *International Journal of Environmental Research and Public Health, 16*(9), 1501.
Mazumdar, S., Learnihan, V., Cochrane, T., & Davey, R. (2018). The built environment and social capital: A systematic review. *Environment and Behavior, 50*(2), 119–158.
McCormack, G. R., Koohsari, M. J., Turley, L., Nakaya, T., Shibata, A., Ishii, K., Yasunaga, A., Oka, K., 2019, Evidence for urban design and public health policy and practice: Space syntax metrics and neighborhood walking, Health & Place:102277.
McCormack, G. R., & Shiell, A. (2011). In search of causality: A systematic review of the relationship between the built environment and physical activity among adults. *International Journal of Behavioral Nutrition and Physical Activity, 8*(1), 125.
McPherson, K. E., Kerr, S., McGee, E., Morgan, A., Cheater, F. M., McLean, J., & Egan, J. (2014). The association between social capital and mental health and behavioural problems in children and adolescents: An integrative systematic review. *BMC Psychology, 2*(1), 7.
Moore, S., Daniel, M., Paquet, C., Dubé, L., & Gauvin, L. (2009). Association of individual network social capital with abdominal adiposity, overweight and obesity. *Journal of Public Health, 31*(1), 175–183.
Mouratidis, K., & Poortinga, W. (2020). Built environment, urban vitality and social cohesion: Do vibrant neighborhoods foster strong communities? *Landscape and Urban Planning, 204*, Article 103951.
Mujahid, M. S., Diez Roux, A. V., Morenoff, J. D., & Raghunathan, T. (2007). Assessing the measurement properties of neighborhood scales: From psychometrics to ecometrics. *American Journal of Epidemiology, 165*(8), 858–867.
Muzayanah, I. F. U., Nazara, S., Mahi, B. R., & Hartono, D. (2020). Is there social capital in cities? The association of urban form and social capital formation in the metropolitan cities of Indonesia. *International Journal of Urban.* Sciences:1–25.
Nagel, C. L., Carlson, N. E., Bosworth, M., & Michael, Y. L. (2008). The relation between neighborhood built environment and walking activity among older adults. *American Journal of Epidemiology, 168*(4), 461–468.
Nguyen, D. (2010). Evidence of the impacts of urban sprawl on social capital. *Environment and Planning B: Planning and Design, 37*(4), 610–627.
Nichani, V., Koohsari, M. J., Oka, K., Nakaya, T., Shibata, A., Ishii, K., … McCormack, G. R. (2020). Associations between the traditional and novel neighbourhood built environment metrics and weight status among Canadian men and women. *Canadian Journal of Public Health*.
Nykiforuk, C. I., McGetrick, J. A., Crick, K., & Johnson, J. A. (2016). Check the score: Field validation of street smart walk score in Alberta, Canada. *Preventive Medicine Reports, 4*, 532–539.
Nyqvist, F., Forsman, A. K., Giuntoli, G., & Cattan, M. (2013). Social capital as a resource for mental well-being in older people: A systematic review. *Aging & Mental Health, 17* (4), 394–410.
O'Brien, R. M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality & Quantity, 41*(5), 673–690.

O'donoghue, G., Perchoux, C., Mensah, K., Lakerveld, J., Van Der Ploeg, H., Bernaards, C., Chastin, S. F., Simon, C., O'gorman, D., Nazare, J.-A., 2016, A systematic review of correlates of sedentary behaviour in adults aged 18–65 years: a socio-ecological approach, BMC Public Health 16(1):163.

Orstad, S. L., McDonough, M. H., James, P., Klenosky, D. B., Laden, F., Mattson, M., & Troped, P. J. (2018). Neighborhood walkability and physical activity among older women: Tests of mediation by environmental perceptions and moderation by depressive symptoms. *Preventive Medicine, 116*, 60–67.

Orstad, S. L., McDonough, M. H., Stapleton, S., Altincekic, C., & Troped, P. J. (2017). A systematic review of agreement between perceived and objective neighborhood environment measures and associations with physical activity outcomes. *Environment and Behavior, 49*(8), 904–932.

Ozbil, A., Peponis, J., & Stone, B. (2011). Understanding the link between street connectivity, land use and pedestrian flows. *Urban Design International, 16*(2), 125–141.

Perkins, D. D., Long, D. A., 2002, Neighborhood sense of community and social capital, in: Psychological sense of community, Springer, pp. 291-318.

Rodgers, J., Valuev, A. V., Hswen, Y., & Subramanian, S. (2019). Social capital and physical health: An updated review of the literature for 2007–2018. *Social Science & Medicine, 236*, Article 112360.

Rogers, G. O., & Sukolratanametee, S. (2009). Neighborhood design and sense of community: Comparing suburban neighborhoods in Houston Texas. *Landscape and Urban Planning, 92*(3), 325–334.

Rogers, S., Aytur, S., Gardner, K., & Carlson, C. (2012). Measuring community sustainability: Exploring the intersection of the built environment & social capital with a participatory case study. *Journal of Environmental Studies and Sciences, 2*(2), 143–153.

Rogers, S. H., Gardner, K. H., & Carlson, C. H. (2013). Social capital and walkability as social aspects of sustainability. *Sustainability, 5*(8), 3473–3483.

Roof, K., & Oleru, N. (2008). Public health: Seattle and King County's push for the built environment. *Journal of Environmental Health, 71*(1), 24–27.

Ross, A., & Searle, M. (2019). A conceptual model of leisure time physical activity, neighborhood environment, and sense of community. *Environment and Behavior, 51*(6), 749–781.

Salvo, D., Reis, R. S., Sarmiento, O. L., & Pratt, M. (2014). Overcoming the challenges of conducting physical activity and built environment research in Latin America: IPEN Latin America. *Preventive medicine, 69*, S86–S92.

Sander, T. H. (2002). Social capital and new urbanism: Leading a civic horse to water? *National Civic Review, 91*(3), 213–234.

Sarkar, C., Webster, C., Pryor, M., Tang, D., Melbourne, S., Zhang, X., & Jianzheng, L. (2015). Exploring associations between urban green, street design and walking: Results from the Greater London boroughs. *Landscape and Urban Planning, 143*, 112–125.

Shelton, B. (2012). *Learning from the Japanese city: Looking east in urban design*. Routledge.

Talen, E. (1999). Sense of community and neighbourhood form: An assessment of the social doctrine of new urbanism. *Urban Studies, 36*(8), 1361–1379.

Toohey, A., McCormack, G., Doyle-Baker, P., Adams, C., & Rock, M. (2013). Dog-walking and sense of community in neighborhoods: Implications for promoting regular physical activity in adults 50 years and older. *Health & Place, 22*, 75–81.

Troped, P. J., Starnes, H. A., Puett, R. C., Tamura, K., Cromley, E. K., James, P., … Laden, F. (2014). Relationships between the built environment and walking and weight status among older women in three US States. *Journal of aging and physical activity, 22*(1), 114–125.

Turner, A., 2004, Depthmap 4, a researcher's handbook'.

Werneck, A. O., Collings, P. J., Barboza, L. L., Stubbs, B., & Silva, D. R. (2019). Associations of sedentary behaviors and physical activity with social isolation in 100,839 school students: The Brazilian Scholar Health Survey. *General Hospital Psychiatry, 59*, 7–13.

Won, J., & Lee, J.-S. (2020). Impact of residential environments on social capital and health outcomes among public rental housing residents in Seoul, South Korea. *Landscape and Urban Planning, 203*, Article 103882.

Wood, L., Frank, L. D., & Giles-Corti, B. (2010). Sense of community and its relationship with walking and neighborhood design. *Social Science & Medicine, 70*(9), 1381–1390.

Wood, L., Giles-Corti, B., & Bulsara, M. (2005). The pet connection: Pets as a conduit for social capital? *Social Science & Medicine, 61*(6), 1159–1173.

Zhu, X., Yu, C.-Y., Lee, C., Lu, Z., & Mann, G. (2014). A retrospective study on changes in residents' physical activities, social interactions, and neighborhood cohesion after moving to a walkable community. *Preventive Medicine, 69*, S93–S97.