Urban design and cardio-metabolic risk factors

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Abstract

Accumulating evidence suggests that the built environment may be associated with cardiovascular disease via its influence on health behaviours. The aim of this study was to estimate the associations between traditional and novel neighbourhood built environment metrics and clinically assessed cardio-metabolic risk factors among a sample of adults in Canada. A total of 7,171 participants from Alberta's Tomorrow Project living in Alberta, Canada, were included. Cardio-metabolic risk factors were clinically measured. Two composite built environment metrics of traditional walkability and space syntax walkability were calculated. Among men, space syntax walkability was negatively associated with systolic and diastolic blood pressure (b=-0.87, 95% CI -1.43, -0.31 and b=-0.45, 95% CI -0.86, -0.04, respectively). Space syntax walkability was also associated with lower odds of overweight/obese among women and men (OR=0.93, 95% CI 0.87, 0.99 and OR=0.88, 95% CI 0.79, 0.97, respectively). No significant associations were observed between traditional walkability and cardio-metabolic outcomes. This study showed that the novel built environment metric based on the space syntax theory was associated with some cardio-metabolic risk factors.

Keywords: Urban form; Cardiovascular risk factors; Cardio-metabolic health; Built environment; Physical environment; Space syntax walkability

1. Introduction

Despite temporal trends over the past two decades suggesting a plateauing or reduction in cardiovascular disease burden, cardiovascular disease remains in the two highest-ranked leading causes of non-communicable disease burden and death in North America (Kassebaum et al., 2016; Vos et al., 2020). Modifiable cardio-metabolic risk factors, which lead to the majority of non-communicable diseases, are prevalent in many countries. Therefore, population-level interventions that prevent these cardio-metabolic risk factors are needed to reduce the burden of managing non-communicable diseases (Foy and Mandrola, 2018).

There is potential to support population-wide changes in cardio-metabolic risk factors via implementing universal interventions such as creating health-supportive built environments (Prüss-Ustün et al., 2019). The premise of focusing on the built environment is that environmental changes may enable many people to make daily choices easy and healthy choices via structural features that persist over the long term (Chokshi and Farley, 2014). Neighbourhood built environment characteristics appear to be important for supporting cardio-metabolic health, particularly via their positive association with physical activity (Kärmeniemi et al., 2018; Koohsari et al., 2020).

While promising, much of the previous evidence examining links between the built environment and cardio-metabolic risk factors has been based on US studies. Relatively fewer studies have investigated associations between urban form and cardio-metabolic risk factors in the Canadian context (McCormack et al., 2019). Findings from different geographical contexts may lack generalizability to the local context due to geo-climatic, healthcare systems, and cultural differences between countries. While Canada may be similar to other Western developed countries in terms of its burden of cardio-metabolic risk factors, the intervention approaches needed to address these health issues likely need to reflect context nuances.

Moreover, many studies investigating the built environment and cardio-metabolic risk factors have relied on aggregated or composite built environment indices such as neighbourhood walkability and Walk Score® to estimate walking-friendly built environments (Braun et al., 2016a; Loo et al., 2017). While demonstrating predictive validity, these composite built environment indices are often limited in that they cannot always be easily translated into a form that can inform urban design policy. However, other approaches to creating composite built environment indices exist that are translatable for urban planners (Koohsari et al., 2016).

Therefore, the current study estimated the associations between traditional and novel neighbourhood built environment metrics and clinically-assessed cardio-metabolic risk factors among a sample of adults in Canada. We stratified the analysis by sex, following previous studies showing differences in associations between the built environment and cardio-metabolic risk factors for men and women (Tarlov et al., 2020).

2. Materials and methods

2.1. Design and sample

This study included a secondary analysis of an existing province-wide cohort dataset from Alberta's Tomorrow Project (ATP) conducted in Alberta, Canada (Figure 1). The methods of this cohort study have been presented in detail elsewhere (Robson et al., 2016; Ye et al., 2017). Briefly, from 2000-2008, a random sample (random digit dialling) of Albertan adults 35-69 years with no personal history of cancer and with no intention of leaving Alberta in the following year were invited to participate in the first wave of recruitment for ATP (n=63,486) and were enrolled upon providing informed consent and completing a health and lifestyle survey (n= 31,072). Participants recruited between 2000 and 2007 were invited to complete a follow-up health and lifestyle survey in 2008 (n= 20,707). From 2009-2015, ATP entered the second wave of recruitment, inviting new and existing participants to attend a study centre to collect physical measures and biosamples for biobanking and use in future research. This study involves a cross-sectional analysis of data from participants enrolled in ATP who completed the 2008 health and lifestyle follow-up survey, had physical measures assessed, provided biosamples, and resided in urban areas (n=7171). Compared to Canadian Community Health Survey data, which is considered representative of the general population, ATP participants are found to be older, include more women, and are healthier (Ye et al., 2017). Our participants in general tended to be slightly older in age, had higher education, included fewer males in married or common-law relationships, and fewer males employed full or part-time compared with the original ATP sample from which they were drawn (Ye et al., 2017). The University of Calgary Conjoint Health Research Ethics Board approved this analysis (REB19-1992).

INSERT FIGURE 1 ABOUT HERE

2.2. Health and Lifestyle Survey

The Health and Lifestyle Survey (Survey 2008) included a comprehensive questionnaire that captured information about sociodemographic characteristics, health history and behaviours. Excluding sex, which was used to stratify our analysis, we included all other sociodemographic variables as covariates. We did not include health behaviours and other factors as covariates because our study focused on estimating associations between neighbourhood environment on cardio-metabolic risk factors unadjusted for health behaviours that may mediate the association.

2.3. Physical Measures and Biosample Data

Between 2009 and 2015, participants were invited to attend a study centre where trained ATP staff measured anthropometrics and blood pressure (Ye et al., 2017). Systolic and diastolic blood pressure were measured using the Omron® HEM907XL IntelliSense Automated Professional Digital Blood Pressure Monitor (Omron; Kyoto, Japan). A stadiometer (Seca 214/217) measured sitting or standing height with shoes and head accessories removed. Weight was measured using the Tanita TBF-310 total body composition analyser (Tanita; Tokyo, Japan). Body mass index (BMI; kg/m^2) was calculated from height and weight.

Blood samples were collected from participants in the non-fasting state into the red top, serum separator tube, and EDTA Vacutainers, processed via centrifugation, and then divided into aliquots of plasma, serum, buffy coat, and red blood cells and frozen in cryovials at-80°C. Mid-stream spot urine samples were also collected from participants at the study centre in sterile urine collection cups, aliquoted into cryovials, and frozen at-80°C. From 2017-2020, ATP pulled serum, red blood cell, and urine samples from the biobank for all participants who provided biosamples and sent them to a clinical diagnostic lab (Calgary Lab Services, Calgary, Alberta) for analysis of a panel of clinical markers, including lipid panel (total and high-density lipoprotein (HDL)-cholesterol and triglycerides measured using enzymatic colourimetric assays; low-density lipoprotein (LDL)-cholesterol calculated via the Friedewald equation (Friedewald et al., 1972) and glycated hemoglobin A1c (HbA1c; measured by immunoturbidimetric assay).

Cardio-metabolic risk indicators were initially examined as continuous variables and then using clinical risk-related cut-points to establish risk levels. LDL-cholesterol was categorised into elevated LDL-cholesterol (≥ 3.37 mmol/L) versus optimal/near-optimal (Medicine, 2013). The threshold for at-risk HDL-cholesterol level was <1.04 mmol/L (Medicine, 2013). Triglycerides level was dichotomised to above borderline high triglycerides (≥ 1.70 mmol/L) versus normal (Medicine, 2013). Raised blood pressure was defined as systolic ≥140 or diastolic ≥90 (Observatory, 2021). Participants were considered to have elevated HbA1c if the measured HbA1c was ≥6.5% (Punthakee et al., 2018). The BMI cut-off value of 25 kg/m^2 was used to dichotomise participants as overweight versus normal weight (World Health Organization, 2016).

2.4. Neighbourhood Built Environment Metrics

Two composite built indices of traditional walkability and space syntax walkability were included. Similar to previous studies (Carlson et al., 2016), the traditional walkability index calculated as the sum of the z-scores of population count, 3-way intersection, 4-way intersection, and business destinations: Traditional walkability = [z(population count) + z(3-way intersection) + z(4-way intersection) + z(business destinations)].

Geographic information systems [ArcGIS Pro 2.2] (ESRI, US) was used to estimate population count, counts of 3- and 4-way intersections, and business destinations within a 400m radius (circular buffer) of geocoded 6-digit residential postal codes of participants in 2008 (in the form of points, not polygons). Due to confidentiality, complete household street address information was unavailable; however, geocoded urban postal codes may provide valid estimates of household geographical location within the Canadian urban context (Bow et al., 2004). The geographical area of Canadian urban residential postal codes usually is from one apartment building to one city block (Postal Code, 2017). A previous study found that urban postal codes provide a reasonable estimate of household location in Canada (Bow et al., 2004). The geocoding of the 6-digit residential postal code was undertaken using the CanMap Postal Code Suite (Desktop Mapping Technologies Inc.; DMTI). A 400m buffer represents the approximate distance travelled after 5 minutes of walking (Mackenbach et al., 2019). Population count was calculated by the Statistics Canada 2006 census dissemination block-level data. Provincial street network file from the 2008 DMTI Spatial CanMap Route Logistics was used to assess the counts of 3- and 4-way intersections within the buffers. An enhanced point of interest file from DMTI Spatial CanMap Route Logistics was used as a data source for estimating business destinations.

Seventy-six Standard Industrial Classification (SIC) codes of business destinations were selected to estimate counts of destinations within the buffer. Destinations identified from SIC codes have an acceptable agreement within the Canadian context compared with field observations (Paquet et al., 2008).

Space syntax walkability was measured using the following formula (Koohsari et al., 2016): Space syntax walkability = $z[z(\text{population count}) + 2 \times z(\text{street integration})]$

Space syntax measure of street integration was calculated for each street segment using Axwomen (Jiang, 2012) and DepthMap (Turner, 2004) software, considering all the other street segments within a 1.6 km circular buffer distance from its centre. Space syntax measures are based on the concept of "axial lines", which correspond to lines of sight (Liu and Jiang, 2012). Space syntax measure of street integration represents how syntactically close a street segment is to other streets in the network (Klarqvist, 2015). Fewer changes in directions are needed to reach a highly integrated street segment, whereas less integrated street segments require more turns to arrive at one's destination (Kostakos, 2010). Intersection density and integration are similar in that both are concerned with street layouts. However, they are very different in the ways they operationalise street layouts. Intersection density is a metric measure, while integration is a relational unitless measure that quantifies how each street is accessible from other streets in terms of the number of turns to make (Baran et al., 2008; Koohsari et al., 2016). Figure 2 shows (a) a neighbourhood block schematic, (b) its axial lines, and (c) the levels of integration for streets.

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2.5. Statistical Analysis

Covariates and built environment indices were analysed using descriptive statistics. Independent t-tests and Pearson's chi-square test were used to compare these variables between women and men. Pearson's correlation coefficient between traditional walkability and space syntax walkability was calculated. Multivariable Tobit regression models were used to estimate the associations between each built environment metric and each cardio-metabolic outcome adjusting for covariates (*b* = unstandardised regression coefficients and 95% CI). Compared to linear regression, Tobit regression provides more accurate estimates of associations when measures of a continuous outcome are censored or truncated and right-skewed (Boulton and Williford, 2018). We used Tobit regression because values for each cardio-metabolic continuous outcome were censored at the lower limit (theoretically valid biological values ≥0) and the distributions for these outcomes were right-skewed. Estimated associations from Tobit regression are based on the uncensored latent outcome (not the observed outcome) but can be interpreted the same as estimates derived from linear regression. Multivariable logistic regressions were used to estimate the odds ratios (ORs) and 95% confidence intervals (CIs) for the associations between each built environment metric and each binary cardio-metabolic outcome adjusting for covariates. Furthermore, each built environment metric was examined separately in each model. A complete-case analysis was chosen because the percentage of missing data for our variables of interest was low (<4%) (Jakobsen et al., 2017). Analyses were conducted using Stata 15.0 (Stata Corp., College Station, TX, US), and the level of significance was set at $p < 0.05$.

3. Results

Table 1 shows the characteristics of the study participants. Approximately 67% of the sample were women (n=4,805), 75% were married or had live-in partners, 18% had some or entire high school training, 90% were Caucasian, 68% were employed (full-time or part-time), 94% were non-smokers, and 48% reported an annual household income of >$100,000. In this sample, 24% had elevated LDL-cholesterol, 15% had low HDL-cholesterol levels, 43% had elevated triglycerides, 14% had elevated blood pressure, 7% had elevated HbA1c, and 65% were overweight/obese. There were significant differences ($p < 0.05$) in several sociodemographic characteristics, including age, marital status, highest education level, and annual household income between women and men. No significant differences ($p < 0.05$) were found in the neighbourhood built environment metrics between women and men (Table 2). There were significant differences in the participants' clinically-assessed cardio-metabolic risk factors between women and men (Appendix Table 1). The correlation between traditional walkability and space syntax walkability was 0.77 ($p < 0.01$). The correlations between street integration and the counts of 3- and 4-way intersections were 0.31 ($p < 0.01$) and 0.61 ($p < 0.01$), respectively.

INSERT TABLES 1 & 2 ABOUT HERE

Table 3 shows the associations of neighbourhood built environment metrics with cardio-metabolic risk factors among women and men. After adjusting for covariates, space syntax walkability was negatively associated with systolic and diastolic blood pressure among men (*b*=-0.87, 95% CI -1.43, -0.31, p = 0.002 and *b*=-0.45, 95% CI -0.86, -0.04, p = 0.030, respectively). No significant associations were observed among women.

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Table 4 presents the logistic regression analysis for the associations of neighbourhood built environment metrics with the binary cardio-metabolic risk factors among women and men. Space syntax walkability was associated with lower odds of overweight/obese among women and men (OR=0.93, 95% CI 0.87, 0.99, p = 0.010 and OR=0.88, 95% CI 0.79, 0.97, p = 0.015, respectively). There were no significant associations between any built environment metrics and elevated LDL-cholesterol, low HDL-cholesterol, elevated triglycerides, elevated blood pressure, and elevated HbA1c for women or men.

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4. Discussion

No previous studies have linked the novel space syntax built environment metrics with cardio-metabolic clinical risk factors to the best of our knowledge. Our findings showed that space syntax walkability was associated with lower odds of being overweight/obese in women. Additionally, the novel composite index of space syntax walkability was negatively associated with systolic and diastolic blood pressure and the odds of being overweight/obese among men.

Several previous studies explored the associations between built environment characteristics, lipid profile, blood pressure, and HbA1c (Braun et al., 2016a; Braun et al., 2016b; Loo et al., 2017; Méline et al., 2017). For instance, in a cross-sectional study undertaken in Canada, compared with the lowest quartile of walkability, for all age groups combined, residents from neighbourhoods in the highest quartile of walkability had significantly lower systolic and diastolic blood pressure, higher HDL-cholesterol, and lower HbA1c (Loo et al., 2017). In the US, a study found that higher Walk Score® was cross-sectionally associated with lower blood pressure; however, an increase in Walk Score® was associated with increases in triglycerides and blood pressure over time (Braun et al., 2016a). While findings from these studies provide some support for our overall finding that specific neighbourhood built environment characteristics are associated with cardio-metabolic risk factors, they differ in that we found no associations with LDL-cholesterol, HDL-cholesterol, triglycerides, or HbA1c. The exact reasons for these differences remain speculative. Changes in these risk factors may be less sensitive to minor differences in the neighbourhood built environment metrics, or the lack of associations in this study could also likely be due to limited geographic variability. Additionally, although diastolic and systolic blood pressure as a continuous measure was inversely associated with SSW in men, there were no significant associations when blood pressure measures were dichotomized using a clinically meaningful cut-point. Therefore, it is entirely possible that null 'total effects' could mask important indirect mediators. For example, a walkable built environment may promote transport walking but be inversely associated with leisure-based physical activities hiding significant associations for some health outcomes when only total effects are studied. Further research is needed to shed light on this issue.

Our study may add to previous findings by testing how the novel built environment metrics based on the space syntax theory are associated with cardio-metabolic risk factors. Our findings suggest that space syntax derived walkability may better predict cardio-metabolic risk factors than a traditional walkability index. Space syntax walkability has several advantages which facilitate translating evidence in the built environment and health to urban design and planning practice. First, space syntax built environment metrics are less data-dependent and can be calculated using readily available network spatial data, which can enhance the replicability of the studies across geographical locations (Koohsari et al., 2016). Traditional walkability measures incorporate information from multiple data sources that are not always available, complete, or in the same format for all geographical locations. Second, space syntax metrics have been widely used in urban design and planning practice for decades among built environment professions (Karimi, 2012) but has only recently been applied in research investigating health outcomes. Finally, space syntax offers metrics of the built environment that can be used to identify optimal locations for the planning and placement of destinations to better support walking and other physical activities (Koohsari et al., 2019). Notably, based on the theory of natural movement in space syntax, street layouts can predict pedestrian flow and attract destinations (Hillier et al., 1993). This ability has practical meaning for urban designers because street layouts are more difficult to modify than destinations.

Our results showed that the novel space syntax built environment metric was associated with obesity status (but not BMI as a continuous variable) in women and men. There are mixed findings on the associations between the walkable built environment and weight status measures (Mackenbach et al., 2014; Paulo Dos Anjos Souza Barbosa et al., 2019; Yang et al., 2021). While several studies demonstrated a negative association between the traditional walkability indices and BMI or waist circumference (Hajna et al., 2018; Loo et al., 2017; McCormack et al., 2018; Müller-Riemenschneider et al., 2013), some other studies reported null findings (Braun et al., 2016a; Duncan et al., 2015). Traditional walkability indices, including neighbourhood walkability and Walk Score®, are usually calculated based on built environment values within certain buffer distances such as 800m, 1km, and 1.6 km around participants' residential location (Frank et al., 2010; Walk Score, 2020). Therefore, it is possible that traditional walkability indices may not truly detect the spatial areas within which people are physically active (Koohsari et al., 2018). Note, however, that other conceptual and operational definitions of traditional walkability indices exist (Forsyth, 2015). Thus, we cannot make assumptions about the predictive validity of these other measures based on the findings related to the traditional walkability index tested in our study. Space syntax metrics conceptualise the built environment by considering how each space is topologically integrated into the spaces' network. Space syntax metrics can inherently represent geographical spaces that are likely to increase or decrease cardio-metabolic risk via the influence of the network on people's daily activities. Nevertheless, one previous study conducted in Australia found no significant association between space syntax walkability and weight change over four years (Koohsari et al., 2018). However, they used self-reported weight measures, possibly subject to recall bias. Further longitudinal research is needed to explore how novel space syntax built environment metrics may be associated with clinical weight measures over time. Additionally, while space syntax walkability does not include a measure of destinations, the traditional walkability index does include destination count. However, counting destinations within a given distance of participant's homes does not reflect other qualities of destinations, which may influence their use.

This study has some limitations. Causal relationships cannot be inferred from our cross-sectional analysis. The built environment metrics were calculated by defining spatial buffers, which may not match the actual built environment to which people are exposed (Holliday et al., 2017). Depending on their level of mobility, residents are exposed to various built environment characteristics in their daily activities (Kwan, 2013). Future studies using a global positioning system can precisely identify and conceptualise people's activity spaces (Perchoux et al., 2019). Furthermore, as our study relied on existing data, we were not able to include all hypothesised cardio-metabolic risk factors. Due to the data availability, we could not elaborate on the study sample's representativeness. Given that our study was intended to be hypothesis-generating and essentially exploratory, we did not attempt to examine mediators of the relationship between built environment measures and cardiometabolic outcomes, nor did we adjust for the type 1 error rate. Replication is needed to confirm our results. The study's strengths include using the novel neighbourhood built environment metrics and examining the clinically-assessed cardio-metabolic risk factors in relatively large samples of men and women.

5. Conclusions

In conclusion, the present study showed that the novel built environment metric based on the space syntax theory was associated with some cardio-metabolic risk factors, including blood pressure and weight status. One implication of these findings is that it might be possible to identify neighbourhoods with poorly built environments and target these environments for interventions specific to improving the cardio-metabolic risk factors. Further studies are needed to elucidate the pathways between neighbourhood built environment and cardio-metabolic risk factors.

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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 the Space Syntax Limited company.

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Table 1. Characteristics of study participants of Alberta's Tomorrow Project

Variable	Total (n=7,171)	Women (n=4,805)	Men (n=2,366)	p^a
	Mean (SD) or N (%)	**Mean (SD) or N (%)**	**Mean (SD) or N (%)**	
Age (years)	54.09 (9.45)	53.3 (9.3)	55.7 (9.5)	0.00
Marital status				
Married or not married, but living with someone	5385 (75.1)	3404 (70.8)	1981 (83.7)	0.00
Separated or divorced	995 (13.9)	812 (16.9)	183 (7.7)	
Widowed	285 (4.0)	233 (4.8)	52 (2.2)	
Single, never married	506 (7.1)	356 (7.4)	150 (6.3)	
Highest education level				
Some or entire high school	1305 (18.2)	917 (19.1)	388 (16.4)	0.00
Some or entire technical college training	2591 (36.1)	1755 (36.5)	836 (35.3)	
Some or entire university degree	2288 (31.9)	1549 (32.2)	739 (31.2)	
Some or entire university postgraduate degree	987 (13.8)	584 (12.2)	403 (17.0)	
Ethnicity				
Caucasian	6463 (90.1)	4333 (90.2)	2130 (90.0)	0.83
Other ethnicities	708 (9.9)	472 (9.8)	236 (10.0)	
Employment status				
Employed (full-time or part-time)	4905 (68.4)	3259 (67.8)	1646 (69.6)	0.14

Unemployed	2266 (31.6)	1546 (32.2)	720 (30.4)	
Current smoking status				
Non-smokers (includes former smokers)	6725 (93.8)	4521 (94.1)	2204 (93.2)	0.13
Smokers	446 (6.2)	284 (5.9)	162 (6.8)	
Annual household income (Canadian Dollars)				
$0 to 49,999	1058 (14.8)	782 (16.3)	276 (11.7)	0.00
$50,000 to 74,999	1081 (15.1)	752 (15.7)	329 (13.9)	
$75,000 to 99,999	1077 (15.0)	713 (14.8)	364 (15.4)	
$100,000 to 149,999	1560 (21.8)	976 (20.3)	584 (24.7)	
$150,000 to 199,999	921 (12.8)	594 (12.4)	327 (13.8)	
$200,000 or more	969 (13.5)	611 (12.7)	358 (15.1)	
Refused to answer	505 (7.0)	377 (7.8)	128 (5.4)	

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[a] Based on independent *t* test or χ2 test.

Table 2. Neighbourhood built environment metrics of participants in of Alberta's Tomorrow Project

	Total (n=7,171)	Women (n=4,805)	Men (n=2,366)
	Mean (SD) **Median (IQR)**	**Mean (SD)** **Median (IQR)**	**Mean (SD)** **Median (IQR)**
Population count	1306.12 (710.19) 1229.56 (655.61)	1302.53 (704.85) 1226.86 (662.16)	1313.42 (720.99) 1234.22 (641.98)
3-way intersection	24.16 (11.82) 23.00 (15.00)	24.08 (11.90) 23.00 (15.00)	24.32 (11.63) 23.00 (15.00)
4-way intersection	7.70 (6.6.9) 6.00 (8.00)	7.74 (6.65) 6.00 (8.00)	7.63 (6.76) 6.00 (8.00)
Business destinations count	3.59 (4.57) 1.00 (6.00)	3.61 (4.56) 2.00 (6.00)	3.55 (4.58) 1.00 (6.00)
Traditional walkability	0.00 (2.63) -0.30 (3.13)	-0.00 (2.64) -0.29 (3.14)	0.0 (2.62) -0.33 (3.12)
Space syntax walkability	0.0 (1.00) -0.12 (1.12)	-0.01 (1.01) -0.12 (1.14)	0.02 (0.99) -0.11 (1.08)

	Low-density lipoprotein (LDL)-cholesterol	High-density lipoprotein (HDL)-cholesterol	Triglycerides	Systolic blood pressure	Diastolic blood p
	***b* (95% CI)**	***b* (95% CI)**	***b* (95% CI)**	***b* (95% CI)**	***b* (95% CI**
Among women					
Traditional walkability	-0.01 (-0.02, 0.00)	0.00 (-0.00, 0.01)	0.00 (-0.01, 0.01)	-0.03 (-0.19, 0.12)	-0.02 (-0.13, 0
Space syntax walkability	-0.02 (-0.05, 0.01)	0.01 (-0.01, 0.02)	0.00 (-0.03, 0.03)	-0.33 (-0.73, 0.07)	-0.14 (-0.43, 0
Among men					
Traditional walkability	-0.00 (-0.02, 0.01)	0.00 (-0.00, 0.01)	-0.01 (-0.03, 0.01)	-0.19 (-0.40, 0.03)	-0.06 (-0.21, 0
Space syntax walkability	-0.01 (-0.05, 0.04)	0.01 (-0.01, 0.02)	-0.02 (-0.07, 0.03)	-0.87 (-1.43, -0.31)[a]	-0.45 (-0.86, -0

Note *b*= unstandardised regression coefficients; CI= confidence interval; population count, 3-way intersections, 4-way intersections, business destinations, sp integration were standardised (i.e., z-scores) prior to the regression analysis; All models adjusted for age, marital status, highest education level, ethnicity, em household income; Each built environment attribute was examined separately in each model.

[a] $p < 0.02$.

[b] $p < 0.05$.

	Elevated LDL-cholesterol[a]	Low HDL-cholesterol[b]	Elevated triglycerides[c]	Elevated blood pressure[d]	Ele
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**O**
Among women					
Traditional walkability	0.98 (0.95, 1.00)	0.96 (0.92, 1.00)	1.00 (0.98, 1.02)	1.02 (0.98, 1.05)	1.0
Space syntax walkability	0.96 (0.90, 1.03)	0.89 (0.80, 1.00)	1.00 (0.94, 1.07)	0.98 (0.89, 1.08)	1.0
Among men					
Traditional walkability	1.01 (0.97, 1.05)	1.01 (0.97, 1.04)	1.00 (0.97, 1.03)	0.98 (0.94, 1.02)	1.0
Space syntax walkability	1.01 (0.91, 1.12)	1.04 (0.95, 1.14)	0.97 (0.89, 1.05)	0.90 (0.81, 1.01)	1.0

Note OR= odds ratio; CI= confidence interval; population count, 3-way intersections, 4-way intersections, business destinations, space syntax connectivity, a
(i.e., z-scores) prior to the regression analysis; All models adjusted for age, marital status, highest education level, ethnicity, employment status, current smok
built environment attribute was examined separately in each model; The level of significance was set at $p < 0.05$.

[a] Elevated LDL-cholesterol concentration defined as above borderline high concentration (≥ 3.37 mmol/L) versus optimal/near optimal (<3.37 mmol/L; refere

[b] Low HDL-cholesterol concentration defined as <1.04 mmol/L versus normal (≥1.04 mmol/L; reference group).

[c] Elevated triglyceride concentration defined as ≥ 1.70 mmol/L versus normal (<1.7 mmol/L; reference group).

[d] Elevated blood pressure defined as systolic ≥140 or diastolic ≥90 versus normal (systolic <140 or diastolic <90; reference group).

[e] Elevated Hemoglobin A1c concentration (HbA1c) defined as ≥6.5% versus normal (<6.5%; reference group).

[f] Overweight/obese defined as body mass index ≥25 kg/m^2 versus normal (<25 kg/m^2; reference group).

[g] $p < 0.02$.

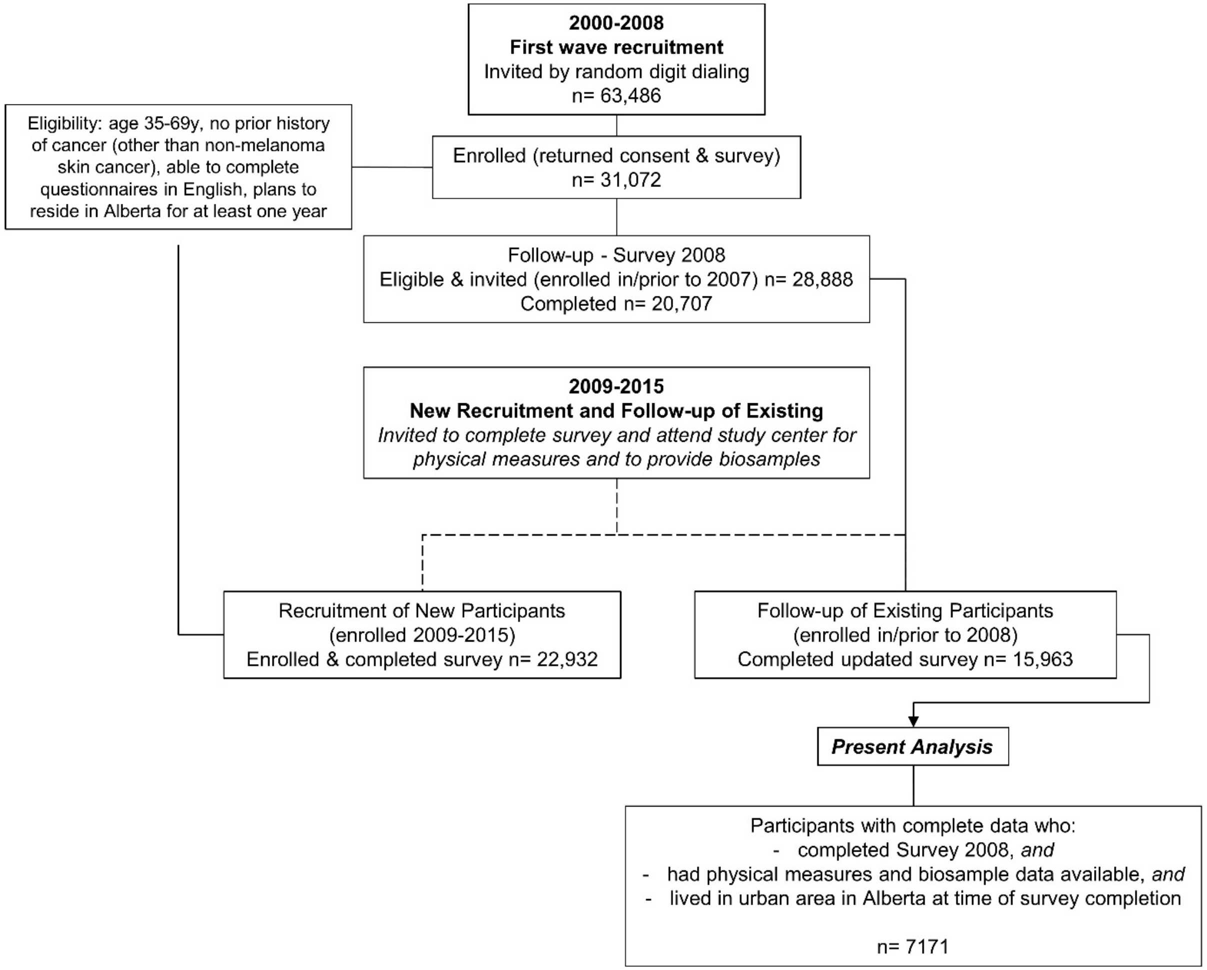

Figure 1. Participants' recruitment process

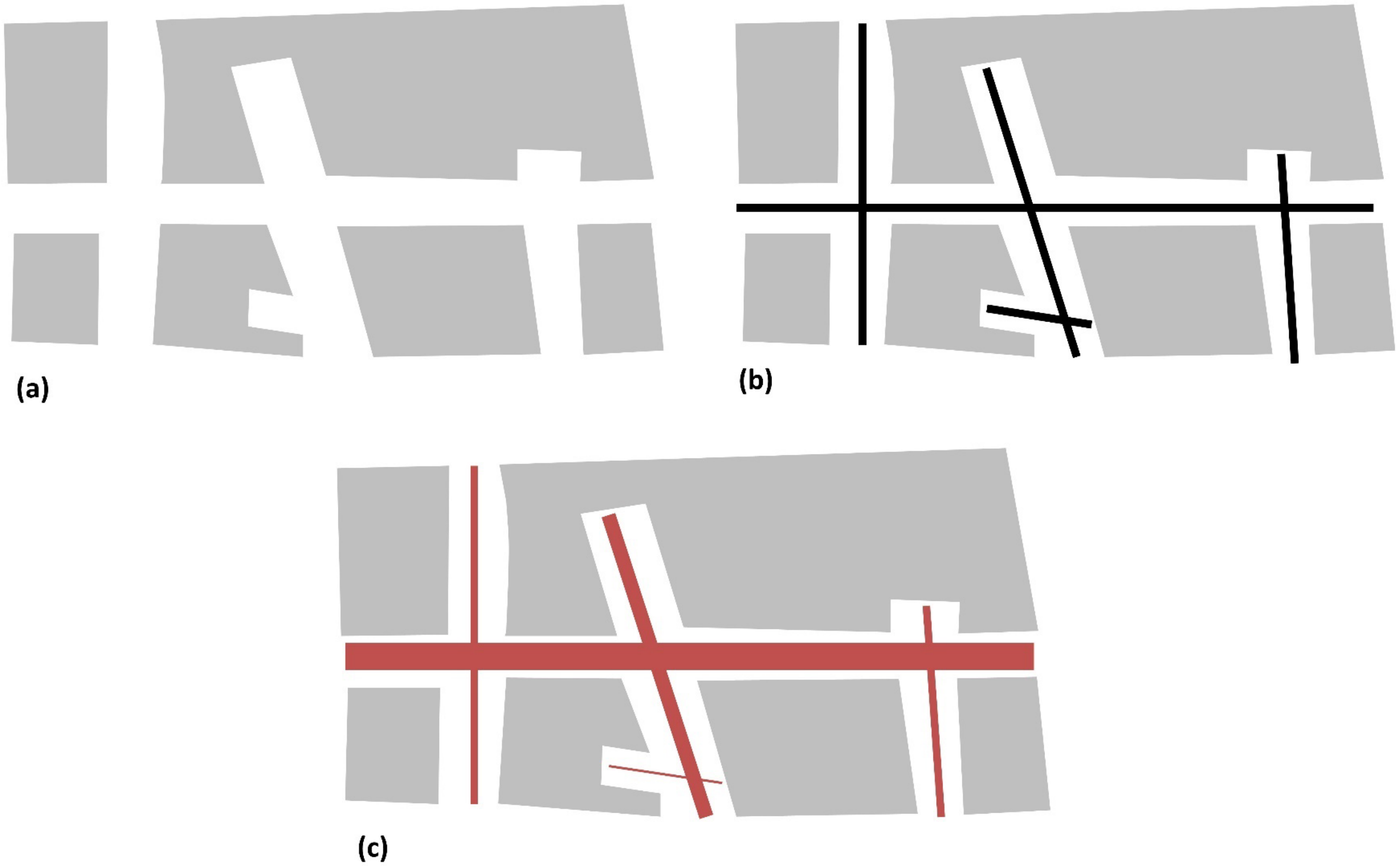

Figure 2. (a) a neighbourhood block, (b) its axial lines (which correspond to lines of sight), and (c) the levels of integration for streets which represent how syntactically close a street segment is to other streets in the network (thicker lines show higher integration level)

Appendix Table 1. The participants' clinically-assessed cardio-metabolic risk factors, in Alberta's Tomorrow Project participants

Variable	Total (n=7,171)	Women (n=4,805)	Men (n=2,366)	p^a
	Mean (SD) or N (%)	**Mean (SD) or N (%)**	**Mean (SD) or N (%)**	
Low-density lipoprotein (LDL)-cholesterol	2.73 (0.98)	2.82 (0.93)	2.56 (1.05)	0.00
High-density lipoprotein (HDL)-cholesterol	1.49 (0.45)	1.62 (0.44)	1.24 (0.35)	0.00
Triglycerides	1.83 (1.12)	1.68 (1.02)	2.14 (1.23)	0.00
Systolic blood pressure	121.92 (14.92)	118.84 (14.57)	128.18 (13.59)	0.00
Diastolic blood pressure	73.81 (9.90)	72.92 (9.86)	75.61 (9.74)	0.00
Hemoglobin A1c	5.66 (0.95)	5.63 (0.85)	5.71 (1.11)	0.00
Body mass index	27.59 (5.56)	27.19 (5.99)	28.38 (4.47)	0.00

[a] Based on independent *t* test.