5 Relationships between Outdoor Walking Levels and Neighbourhood Built-Environment Attributes

The Case of Older Adults in Birmingham, UK

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5.1 INTRODUCTION

Outdoor walking is one of the forms of physical activity that takes place in urban areas. Outdoor walking may be undertaken for different purposes, such as walking as a means of transport and walking for recreation (Zandieh et al., 2017b). Walking has well-known positive impacts on people's health (Lee and Buchner, 2008; Sugiyama and Thompson, 2007), and for this reason people (especially those who are at risk for health problems, such as older adults) are advised to take outdoor walks (Age UK, 2016; Department of Health, 2011).

Previous studies (Handy et al., 2002; Saelens and Handy, 2008) have shown that levels (duration) of outdoor walking are related to neighbourhood built-environment attributes, which can be divided into macro built-environment attributes and micro built-environment attributes (Sallis et al., 2011). Macro built-environment attributes, such as residential density, land-use mix and intensity, street connectivity and retail density, shape the overall design and structure of a neighbourhood (Sallis et al., 2011). Micro built-environment attributes, such as safety, pedestrian infrastructure and aesthetics, shape characteristics of walking routes in a neighbourhood (Sallis et al., 2011). Availability of Geographic Information System (GIS) and GIS-based land use and transportation data provides opportunities for developing objective measures of attributes of the macro built-environment (Leslie et al., 2007) and for better reflection about the actual built-environment. GIS-based data on micro built-environment attributes is, however, often unavailable (Leslie et al., 2007), and these built-environment attributes are usually measured subjectively (Sallis et al., 2011).

While significant relationships between outdoor walking levels and GIS-measured macro and perceived micro built-environment attributes have already been investigated (Sugiyama et al., 2015; Van Cauwenberg et al., 2012; Zandieh et al., 2016, 2017a), correlations among (within group) and between (between groups) these built-environment attributes themselves have received less attention in past research on outdoor walking. For example, Zandieh et al. (2016, 2017a) have shown that certain GIS-measured neighbourhood land use (green space and recreation centres) intensity – as macro built-environment attributes – and perceived neighbourhood safety, pedestrian infrastructure (quietness) and aesthetics – as micro built-environment attributes – are positively related to levels of outdoor walking of older adults in Birmingham (UK). They have also shown that certain GIS-measured neighbourhood land use (schools and industries) intensity and street connectivity – as macro built-environment attributes – are negatively related to outdoor walking levels of older adults in Birmingham. Similarly, other studies (Sugiyama et al., 2015; Van Cauwenberg et al., 2012) have found significant relationships between outdoor walking levels and GIS-measured macro and perceived micro built-environment attributes (e.g. street connectivity and safety, respectively) without investigating correlations among and between the neighbourhood built-environment attributes themselves.

It is likely, however, that neighbourhood built-environment attributes also influence each other mutually. For instance, it has been qualitatively found that neighbourhood residential density affects the amount of green space in neighbourhoods (Zandieh et al., 2017a), that high levels of traffic noise reduce perceived neighbourhood quietness (Zandieh et al., 2016) and that the presence of litter and broken windows (low aesthetic level) leads to perceptions of unsafety (Loukaitou-Sideris, 2006). These findings suggest that there could be correlations among macro (e.g. residential density and green space) and among micro (e.g. traffic conditions and quietness) built-environment attributes themselves.

Similarly, correlations may exist between macro and micro built-environment attributes: the presence of (macro) green space offers (micro) beautiful views (Zhou and Parves Rana, 2012), while conversely the presence of industries provides dreary views in neighbourhoods (Zandieh et al., 2016); and the presence of some types of land use in a neighbourhood, such as schools, generates traffic hazards (Zandieh et al., 2017a). Similarly, neighbourhood street connectivity (presence of junctions) affects perceptions of traffic conditions (Gomez et al., 2010) and perceived levels of traffic noise (Quartieri et al., 2010). Such correlations among and between neighbourhood built-environment attributes could influence significant relationships between outdoor walking levels and other neighbourhood built-environment attributes. In other words, some neighbourhood built-environment attributes would be related to outdoor walking levels through their correlations with other neighbourhood built-environment attributes.

Examining correlations among and between neighbourhood built-environment attributes would be helpful in undertaking urban planning interventions for supporting outdoor walking since it makes clear the effects of neighbourhood built-environment attributes on outdoor walking levels. As a consequence, urban planners have a better understanding of how to modify the built

environment in ways that increase the positive (or decrease negative) influences of neighbourhood built-environment attributes on levels of outdoor walking.

Frank et al. (2005) have addressed correlations among GIS-measured macro built-environment attributes. However, correlations among perceived micro built-environment attributes have been rarely examined in studies on outdoor walking. It is important to examine correlations among perceived micro built-environment attributes, because people's perceptions of their environment may differ according to their personal details (e.g. age, gender and cultural background). Therefore, correlations among perceived micro built-environment attributes (and also between GIS-measured macro and perceived micro built-environment attributes) may differ for different social groups, including older adults.

The research we describe in this chapter had two aims: (1) to illustrate the capacity of GIS for generating objective measures of macro built-environment attributes; and (2) to use GIS-measured macro built-environment attributes, together with perceived micro built-environment attributes, to examine correlations among and between neighbourhood built-environment attributes in order to better understand how to increase positive (or to decrease negative) influences of neighbourhood built-environment attributes on outdoor walking levels. To achieve our second aim, we focused our research on one specific social group: older adults living in Birmingham (UK). We had three reasons for this focus: inactivity has been identified as one of the biggest public health problems in Birmingham (Birmingham Public Health, 2017), inactivity is prevalent among older adults (WHO, 2017) and outdoor walking is an excellent form of physical activity for them (Centers for Disease Control and Prevention, 1999; Cunningham and Michael, 2004).

5.2 CASE STUDY AREA: BIRMINGHAM (UK)

Birmingham is located in the West Midlands of England, UK (Figure 5.1) and lies equidistant from the main ports of England (i.e. Bristol, Liverpool, Manchester and London; William, 2010). It consists of 40 electoral wards (Figure 5.1) and has a population over one million

FIGURE 5.1 Left: Geographic locations of the West Midlands and Birmingham in the UK (adapted from (ONS Geography GIS and Mapping Unit, 2011). Right: Birmingham electoral wards (Google Earth™ mapping service (<http://earth.google.com>) and OS open data Boundary-Line® © Crown copyright/database right 2012).

inhabitants. It is the second-largest city in the UK. Birmingham is a major regional centre for business, retail and leisure activities (Brookes et al., 2012) and is also home to some of Britain's major manufacturing industries: motor vehicles, bicycles, electrical equipment, paints, guns and many other metal products (William, 2010). After Liverpool and Manchester, Birmingham has been identified as the third-most deprived UK Core City (Birmingham City Council, 2010).

Birmingham has a diverse population, with over 42% of its inhabitants being classified as belonging to an ethnic group other than 'white-British' (Birmingham City Council, 2013). Nearly one-third of Birmingham's residents are older adults, almost three-quarters of whom enjoy fairly good to good health, even though this figure is below regional and national averages (Birmingham City Council, 2017).

BOX 5.1 Case Study Area

Birmingham is located in the West Midlands of England (UK). It consists of 40 electoral wards and has a population of over one million inhabitants, making it the second-largest city in the UK. It is a major regional centre for business, retail and leisure activities (Brookes et al., 2012) and is also home to some of the country's major industries (William, 2010). After Liverpool and Manchester, it has been identified as the third-most deprived UK Core City (Birmingham City Council, 2010). Birmingham has a diverse population, with over 42% of residents having an ethnicity other than 'white-British' (Birmingham City Council, 2013). Nearly one-third of Birmingham's residents are older adults, almost 75% of whom enjoy (fairly)

good health, but this figure is below regional and national averages (Birmingham City Council, 2017).

5.3 METHODS

For this study, we made use of secondary data (Zandieh et al., 2016 and 2017a). Macro built-environment attributes were measured using GIS-based land use and transportation data (Zandieh et al., 2017a), while perceived micro built-environment attributes were measured by questionnaire (Zandieh et al., 2016). Detailed information on participant recruitment, data collection and the measurement process has been provided by Zandieh et al. (2016, 2017a). A brief description of data used in the study can be found further on in this section.

High- and low-deprivation areas* were surveyed by questionnaire in Birmingham in 2012, with a convenience sampling approach used to recruit participants from social centres (community centres, University of the Third Age, libraries, etc.). All participants chosen were 65 years or over, able to walk, leading independent daily lives, and mentally healthy; speaking language was not an eligibility criterion. The final sample included 173 participants, whose characteristics are summarised in Table 5.1.

* High-deprivation areas are urban areas experiencing high levels of social and economic disadvantage.

TABLE 5.1
Summary of Participants’ Characteristics

Participants’ Characteristics	Total Sample
No. of participants	173 ^a
Age (%):	
75 years and over	48
65–74 years	52
Gender (%):	
Men	43
Women	57
Marital status (%):	
In a relationship	53
Single	47
Ethnicity (%):	
White–British	71
BME groups	29
Educational level (%):	
GCSE and higher	54
Sub-GCSE	35
Perceived health status (%):	
Good	92
Poor	7

Source: Data from Zandieh et al. (2016).
Note: ^a 80 and 93 participants from high- and low-deprivation areas of Birmingham, respectively. BME=black and minority ethnic groups. GCSE=General Certificates of Secondary Education or its equivalent.

5.3.1 DATA ON NEIGHBOURHOOD BUILT-ENVIRONMENT ATTRIBUTES

Data for measuring macro built-environment attributes (i.e. neighbourhood residential density, land-use mix and intensity, street connectivity and retail density) was downloaded from Digimap®/EDINA (national data centre for UK academics) and the UK Office for National Statistics (for 2001 Census data) (see Table 5.2). This data was used to objectively measure macro built-environment attributes by using GIS (explained in Subsection 5.3.2).

To collect data on perceived micro built-environment attributes (i.e. neighbourhood safety, pedestrian infrastructure and aesthetics), a self-administered questionnaire was used (Zandieh et al., 2016). The questionnaire was based on the Neighbourhood Environment Walkability Scale (NEWS) (Saelens et al., 2003a) and further modified to be applicable for older adults in the UK. The questionnaire contained 29 items (those irrelevant to safety, pedestrian infrastructure and aesthetics in connection with walking were removed from the NEWS questionnaire), and each answer was rated on a six-point Likert scale. Seven subscales were included in the questionnaire: safety; five aspects of pedestrian infrastructure (i.e. traffic condition, pavement condition, presence of amenities (benches and public toilets), quietness and air quality); and aesthetics. A NEWS scoring protocol (Saelens et al., 2003a) was used to score the subscales, which means that higher scores indicate

TABLE 5.2
Data Collected for Measuring Macro Built-Environment Attributes

Macro Built-Environment Attribute	Data (Data Source)
Residential density	Number of household spaces (UK Census, 2001): Number of households in each LSOA ^b LSOAs ^b Boundary-Line 2012 (Digimap [®] /EDINA) ^a : GIS-based data (polygons) representing boundary of LSOAs
Land-use mix and intensity, and retail density	OS Points of Interest (PoI) 2016 (Digimap [®] /EDINA) ^a : GIS-based data (points) representing locations of non-residential use (retail, catering, etc.) OS MasterMap 2016–Topography Layer (Digimap [®] /EDINA) ^a : The most accurate GIS-based data representing physical features (e.g. roads and buildings) in the UK
Street connectivity	OS MasterMap 2016–Integrated Transport Network (ITN) layer (Digimap [®] /EDINA) ^a : GIS-based data on road network in the UK OS MasterMap 2016–Urban Path Theme (UP) layer (Digimap [®] /EDINA) ^a : GIS-based data on urban path network appropriate for non-vehicular users (e.g. footpath, subway, cycle path)

Source: Adapted from Zandieh et al., (2017a).

Note: Data on neighbourhood land-use mix and intensity was also used for identifying residential land use and measuring residential density. ^a Digimap[®]/EDINA is the national data centre for UK academics. ^b LSOA = Lower Super Output Area (a relatively homogenous geographic area with population around 1500 residents (McLennan et al., 2011; Payne, 2012)); OS = Ordnance Survey.

a greater appreciation of micro built-environment attributes – safety, pedestrian infrastructure and aesthetics.

5.3.2 DATA ANALYSIS

5.3.2.1 GIS Measures of Macro Built-Environment Attributes

A Geographic Information System (GIS) – ArcGIS 10.4, ESRI[™], Redlands, CA, USA – was used to objectively measure macro built-environment attributes. These neighbourhood built-environment attributes were measured within a home-based neighbourhood – i.e. a 2-km Euclidean buffer area around each participant’s home (Figure 5.2a) (Zandieh et al., 2017a). This buffer area is known to be the one most commonly used for taking outdoor walks (Suminski et al., 2014), and each participant’s outdoor walking level was measured within this area (Zandieh et al., 2016). The ‘buffer’ analysis tool in Arc GIS was used to delineate this area for each participant.

Points of Interest (PoI) data (Table 5.2) was used to create a land use map distinguishing residential and non-residential land use. By using ArcGIS, first PoI were overlain with the Topography Layer (Table 5.2). By considering one use for each building (Rodriguez et al., 2009), non-residential buildings were identified and their relevant plots were digitised. After excluding non-residential buildings and their plots, residential buildings were identified and their relevant plots digitised (Figure 5.2b). All identified boundaries were cross-referenced against images from Google Earth. Area of residential land use (calculated by statistical analysis with the assistance of ArcGIS), data on the number of household spaces and LSOAs Boundary-Line 2012 (Table 5.2), and an equation presented by Zandieh et al. (2017a), were used to measure residential density within each participant’s home-based neighbourhood:

$$RD = \sum_{i=1}^n k_i D_i$$

FIGURE 5.2 (a) A participant's home-based neighbourhood, and (b) residential land use within that participant's home-based neighbourhood.

where:

RD = residential density for a home-based neighbourhood

i = the LSOA

D_i = residential density of the LSOA (total number of household space in the LSOA/total LSOA's residential land use area (hectare))

k_i = the proportion of the LSOA's residential land use area (hectare) located within a home-based neighbourhood against total LSOA's residential land use area (hectare)

n = the number of LSOAs

(Zandieh et al., 2017a, p.6)

For measuring neighbourhood land-use mix, areas of residential and non-residential land use (including catering (eating/drinking) activities, green spaces, recreation centres, social infrastructure, retail plots and buildings, schools and industries; see Figure 5.3) were used. To generate a land-use mix entropy score, the equation used by Stockton et al. (2016) for calculating land-use mix (or “mixedupness”) for London was employed. For measuring land-use diversity, area of non-residential land uses were employed (Zandieh et al., 2017a). Areas of retail plots and buildings within participants' home-based neighbourhoods (Figure 5.3) were measured with the assistance of statistical analysis in ArcGIS and used to calculate neighbourhood retail densities (Zandieh et al., 2017a).

To measure neighbourhood street connectivity, two layers of OS MasterMap (Table 5.2) were employed (Stockton et al., 2016; Zandieh et al., 2017a): an ITN layer (data on the road network of the UK); and a UP layer (data on the urban path network suitable for non-vehicular users; see Figure 5.4a, b). By using ArcGIS, motorways and slip roads were selected and excluded from the ITN layer, as walking on them is prohibited (Department of Transport, 2016; Zandieh et al., 2017a). The ‘Network Analyst’ extension in ArcGIS was used to combine the two layers to generate a pedestrian-route network data set (Figure 5.4c). The points generated in the set represent junctions (Figure 5.4d). Junctions that connect three or more roads/paths within participants' home-based neighbourhoods were identified and counted. Junction density

FIGURE 5.3 Non-residential land use within the participant's home-based neighbourhood and a layout of retail plots and buildings.

was then calculated and used as an indicator for neighbourhood street connectivity (Zandieh et al., 2017a).

5.3.2.2 Statistical Correlations

Pearson correlations among and between neighbourhood built-environment attributes were calculated using IBM® SPSS Statistics 24. For this purpose, the logarithmic transformation of data ($x + 1$) was used in order to improve normality in the data. A p -value < 0.05 was considered statistically significant.

To be able to clearly interpret the degree of correlations among and between neighbourhood built-environment attributes, the strength of Pearson correlations was classified as being either high, fair or weak (see Table 5.3); we used Navarro (2013) as a guide when interpreting correlations. Pearson correlations with p -values ≥ 0.05 were considered to be insignificant correlations. Descriptive statistics were used to compare strength of correlations among and between neighbourhood built-environment attributes.

BOX 5.2 Methods Applied in the Chapter

The methods section of this chapter illustrates the capacity of GIS – ArcGIS 10.4 (ESRI, Redlands, CA) – for generating objective measures of one group of neighbourhood built-environment attributes: macro built-environment attributes (residential density, land-use mix and intensity, street connectivity and retail density). The methods section describes how to combine GIS-based land-use and transportation data by applying simple GIS techniques, such as overlaying data, buffer analysis, digitizing plots, statistical analysis and the 'Network Analyst' (extension) in ArcGIS. Data included the number of household spaces; LSOAs Boundary-Line 2012; OS Points of Interest (PoI) 2016; OS MasterMap 2016–Topography Layer; OS MasterMap 2016–Integrated Transport Network (ITN) layer; and OS MasterMap 2016–Urban Path Theme (UP) layer. Data was collected from the UK Census 2001 and Digimap/EDINA (the national data centre for UK academics).

FIGURE 5.4 Generating a pedestrian-route network and identifying junctions.

TABLE 5.3
Classification of Pearson Correlations

Correlation strength	Range correlation coefficient
High	± 0.70 to ± 1.00
Fair	± 0.40 to ± 0.70
Weak	± 0.00 to ± 0.40

The GIS method applied in this chapter has some limitations:

- Data from different years (i.e. 2001, 2012 and 2016) was used.
- Generated data for residential and non-residential land use is coarse because only one use was assigned to each building; some buildings may have more than one use.
- Defined home-based neighbourhood (2-km buffer) for generating GIS-based macro built-environment attributes is not necessarily the same as a respondent's perception of 'neighbourhood' when measuring perceived micro built-environment attributes.

5.4 RESULTS

5.4.1 CAPACITY OF GIS FOR MEASURING MACRO BUILT-ENVIRONMENT ATTRIBUTES

Subsection 5.3.2 illustrates the capacity of GIS for generating objective measures of macro built-environment attributes. It describes how to use ArcGIS and point data on locations of non-residential uses, from which a land-use map can be generated. It also shows how applying ArcGIS techniques – such as buffer analysis, overlaying data, digitizing, statistical analysis, selecting and extracting data (e.g. non-residential plots and motorways) and Network Analyst – facilitates manipulating and combining data to generate objective measures of macro built-environment attributes.

5.4.2 CORRELATIONS AMONG AND BETWEEN NEIGHBOURHOOD BUILT-ENVIRONMENT ATTRIBUTES

Table 5.4 summarises the strength of correlations among and between neighbourhood built-environment attributes. The correlations themselves are presented in Tables 5.5 through 5.7. In total, 153 correlations were examined (including 55 correlations among/within GIS-measured macro built-environment attributes, 21 correlations among/within perceived micro built-environment attributes and 77 correlations between GIS-measured macro and perceived micro built-environment attributes); see Table 5.4.

As Table 5.4 shows, most high correlations were found within GIS-measured macro built-environment attributes. There is no high correlation among perceived micro built-environment attributes. Most correlations among perceived micro built-environment attributes are fair correlations. Almost half of the correlations between GIS-measured macro and perceived micro attributes are weak correlations. Nevertheless, there are some high and fair correlations between GIS-measured

TABLE 5.4
Correlation Strength Among/Within and Between GIS-Measured Macro and Perceived Micro Built-Environment Attributes

Correlations	Within Macro	Within Micro	Between Macro and Micro	Total No. of Correlations
Number of correlations (<i>n</i>)	55	21	77	153
High correlation (%)	38	0	7	17
Fair correlation (%)	35	67	27	35
Weak correlation (%)	20	29	48	35
Insignificant correlation (%)	7	4	18	12

Note: Macro=GIS-measured macro built-environment attributes, micro=perceived micro built-environment attributes.

TABLE 5.5
Correlations Among GIS-Measured Macro Built-Environment Attributes

GIS-Measured Macro Built- Environment Attribute	Land Use Intensity									
	Land- Use Mix	Catering activities	Green Space	Recreation Centres	Social Infrastructure	Retail Activities	Schools	Industries	Street Connectivity	Retail Density
Residential density	0.24 0.002	0.85 0.000	-0.44 0.000	-0.81 0.000	0.62 0.000	0.89 0.000	0.86 0.000	0.79 0.000	0.91 0.000	0.61 0.000
Land-use mix		0.36 0.000	0.19 0.014	-0.40 0.633	0.57 0.000	0.37 0.000	0.15 0.057	0.07 0.366	0.35 0.000	0.34 0.000
Land-use intensity:			-0.36 0.000	-0.65 0.000	0.59 0.000	0.81 0.000	0.82 0.000	0.59 0.000	0.85 0.000	0.82 0.000
Catering activities										
Green space				0.58 0.000	0.00 0.996	-0.47 0.000	-0.54 0.000	-0.73 0.000	-0.58 0.000	-0.16 0.039
Recreation centres					-0.33 0.000	-0.78 0.000	-0.79 0.000	-0.84 0.000	-0.78 0.000	-0.43 0.000
Social infrastructure						0.54 0.000	0.41 0.000	0.21 0.005	0.54 0.000	0.48 0.000
Retail activities							0.81 0.000	0.83 0.000	0.90 0.000	0.62 0.000
Schools								0.77 0.000	0.86 0.000	0.67 0.000
Industries									0.84 0.000	0.36 0.000
Street connectivity										0.61 0.000

Note: This table shows Pearson correlation values; *p*-values are in *italics*. Dark-grey cells show high correlations (correlation coefficient: ± 0.70 to ± 1.00); grey cells show fair correlations (correlation coefficient: ± 0.40 to ± 0.70); light-grey cells show weak correlations (correlation coefficient: ± 0.00 to ± 0.40); and white cells show insignificant correlations.

TABLE 5.6
Correlations Among Perceived Micro Built-Environment Attributes

Perceived Micro Built- Environment Attribute	Pedestrian Infrastructure					
	Traffic Conditions	Pavement Condition	Presence of Amenities	Quietness	Air Quality	Aesthetics
Safety	0.55 <i>0.000</i>	0.38 <i>0.000</i>	0.17 <i>0.023</i>	0.43 <i>0.000</i>	0.31 <i>0.000</i>	0.47 <i>0.000</i>
Pedestrian infrastructure:		0.54	0.31	0.41	0.41	0.58
Traffic conditions		<i>0.000</i>	<i>0.000</i>	<i>0.000</i>	<i>0.000</i>	<i>0.000</i>
Pavement condition			0.21 <i>0.006</i>	0.46 <i>0.000</i>	0.45 <i>0.000</i>	0.52 <i>0.000</i>
Presence of amenities				0.21 <i>0.006</i>	0.10 <i>0.178</i>	0.43 <i>0.000</i>
Quietness					0.40 <i>0.000</i>	0.52 <i>0.000</i>
Air quality						0.41 <i>0.000</i>

Note: This table shows Pearson correlation values; *p*-values are in *italics*. Grey cells show fair correlations (correlation coefficient: ± 0.40 to ± 0.70); light-grey cells show weak correlations (correlation coefficient: ± 0.00 to ± 0.40); and white cells show insignificant correlations.

macro and perceived micro built-environment attributes. Detailed results on all these correlations are presented in the following subsections.

5.4.3 CORRELATIONS AMONG GIS-MEASURED MACRO BUILT-ENVIRONMENT ATTRIBUTES

Table 5.5 summarises the correlations among GIS-measured macro built-environment attributes. Except for green space and recreation centre intensities, all GIS-measured macro built-environment attributes are positively correlated with each other. GIS-measured green space and recreation centre intensities are positively correlated with each other, but there are negative correlations between these two GIS-measured land-use (i.e. green space and recreation centres) intensities and the other GIS-measured macro built-environment attributes of residential density, intensity of other land uses (e.g. retail activities, schools and industries), street connectivity and retail density. This means that as most GIS-measured macro built-environment attributes – e.g. residential density and the land area dedicated to industries) – increase, the land area dedicated to green space and recreation centres may shrink.

5.4.4 CORRELATIONS AMONG PERCEIVED MICRO BUILT-ENVIRONMENT ATTRIBUTES

Table 5.6 shows correlations among perceived micro built-environment attributes. Except for the correlation between presence of amenities and air quality, there are positive correlations among all perceived micro built-environment attributes. Perceived aesthetics is the only perceived micro built-environment attribute that correlates fairly with all other micro built-environment attributes. After aesthetics, traffic conditions are fairly correlated with other perceived micro built-environment attributes (except for one aspect of pedestrian infrastructure: presence of amenities). Therefore, according to our study, as positive perceptions of traffic conditions improve, with the exception of

presence of amenities (one aspect of pedestrian infrastructure), positive perceptions of the other perceived micro built-environment attributes also improve.

5.4.5 CORRELATIONS BETWEEN GIS-MEASURED MACRO AND PERCEIVED MICRO BUILT-ENVIRONMENT ATTRIBUTES

Table 5.7 gives an overview of correlations between GIS-measured macro and perceived micro built-environment attributes. In general, most GIS-measured macro built-environment attributes (i.e. residential density, land-use intensity (but not social infrastructure intensity), street connectivity, and retail density) are correlated with most perceived micro built-environment attributes. GIS-measured land-use mix is the only GIS-measured macro built-environment attribute that is

TABLE 5.7
Correlations Between GIS-Measured Macro and Perceived Micro Built-Environment Attributes

GIS-Measured Macro Built- Environment Attribute	Perceived Micro Built-Environment Attribute						
	Pedestrian Infrastructure						Aesthetics
	Safety	Traffic Conditions	Pavement Condition	Presence of Amenities	Quietness	Air Quality	
Residential density	-0.37 <i>0.000</i>	-0.39 <i>0.000</i>	-0.40 <i>0.000</i>	-0.32 <i>0.000</i>	-0.42 <i>0.000</i>	-0.29 <i>0.000</i>	-0.73 <i>0.000</i>
Land-use mix	-0.50 <i>0.548</i>	0.01 <i>0.856</i>	-0.02 <i>0.780</i>	0.10 <i>0.196</i>	0.01 <i>0.927</i>	0.02 <i>0.784</i>	-0.07 <i>0.358</i>
Land-use intensity:	-0.39 <i>0.000</i>	-0.35 <i>0.000</i>	-0.28 <i>0.000</i>	-0.31 <i>0.000</i>	-0.30 <i>0.000</i>	-0.28 <i>0.000</i>	-0.62 <i>0.000</i>
Catering activities							
Green space	0.25 <i>0.001</i>	0.33 <i>0.000</i>	0.31 <i>0.000</i>	0.38 <i>0.000</i>	0.25 <i>0.001</i>	0.12 <i>0.130</i>	0.56 <i>0.000</i>
Recreation centres	0.43 <i>0.000</i>	0.47 <i>0.000</i>	0.47 <i>0.000</i>	0.28 <i>0.000</i>	0.48 <i>0.000</i>	0.33 <i>0.000</i>	0.75 <i>0.000</i>
Social infrastructure	-0.09 <i>0.245</i>	-0.11 <i>0.165</i>	-0.09 <i>0.218</i>	0.09 <i>0.256</i>	-0.19 <i>0.012</i>	-0.02 <i>0.811</i>	-0.31 <i>0.000</i>
Retail activities	-0.41 <i>0.000</i>	-0.37 <i>0.000</i>	-0.40 <i>0.000</i>	-0.23 <i>0.003</i>	-0.39 <i>0.000</i>	-0.28 <i>0.000</i>	-0.67 <i>0.000</i>
Schools	-0.44 <i>0.000</i>	-0.44 <i>0.000</i>	-0.36 <i>0.000</i>	-0.37 <i>0.000</i>	-0.40 <i>0.000</i>	-0.27 <i>0.000</i>	-0.71 <i>0.000</i>
Industries	-0.43 <i>0.000</i>	-0.45 <i>0.000</i>	-0.49 <i>0.000</i>	-0.37 <i>0.000</i>	-0.41 <i>0.000</i>	-0.31 <i>0.000</i>	-0.75 <i>0.000</i>
Street connectivity	-0.44 <i>0.000</i>	-0.41 <i>0.000</i>	-0.38 <i>0.000</i>	-0.34 <i>0.000</i>	-0.36 <i>0.000</i>	-0.25 <i>0.001</i>	-0.73 <i>0.000</i>
Retail density	-0.26 <i>0.000</i>	-0.20 <i>0.008</i>	-0.15 <i>0.052</i>	-0.17 <i>0.024</i>	-0.16 <i>0.033</i>	-0.21 <i>0.005</i>	-0.40 <i>0.000</i>

Note: This table shows Pearson correlation values; *p*-values are in *italics*. Dark-grey cells show high correlations (correlation coefficient: ± 0.70 to ± 1.00); grey cells show fair correlations (correlation coefficient: ± 0.40 to ± 0.70); light-grey cells show weak correlations (correlation coefficient: ± 0.00 to ± 0.40); and white cells show no correlation. The thick black boundary contains positive significant correlations. All significant correlations outside the thick black boundary are negative correlations.

insignificantly correlated with all perceived micro built-environment attributes. Interestingly, the correlation between GIS-measured green space intensity and perceived air quality is insignificant.

As Table 5.7 shows, excluding GIS-measured green space and recreation centre intensities (thick black boundary), all significant correlations between GIS-measured macro and perceived micro built-environment attributes are negative. Therefore, as GIS-measured macro built-environment attributes (excepting green space and recreation centre intensities) increase, perception of micro built-environment attributes, for example quietness and aesthetics, may decline.

5.5 DISCUSSION

It is important for urban planners to identify relationships between outdoor walking and neighbourhood built-environment attributes, both macro and micro. In doing so, GIS provides urban planners with an opportunity to study these relationships by objectively measuring neighbourhood built-environment attributes. This method is mostly used to measure macro built-environment attributes, since GIS-based land use and transportation data is often available. This chapter shows how applying simple GIS techniques – overlaying data, buffer analysis, digitizing plots, statistical analysis and network analyst in ArcGIS – can help urban planners to integrate various data and produce measures of macro built-environment attributes. Similar methods (applying GIS) for measuring macro built-environment attributes have already been used in studies on outdoor walking (or physical activities) of adults in a number of countries, including the UK (Stockton et al., 2016), the USA (Frank et al., 2005), Australia (Gebel et al., 2009) and New Zealand (Hinckson et al., 2017)).

This chapter also used the generated GIS-measured data to study correlations among and between neighbourhood built-environment attributes in the hope of helping urban planners to better understand how to increase the positive (or decrease the negative) influences of neighbourhood built-environment on outdoor walking.

The results of our study demonstrate strong correlations within GIS-measured macro built-environment attributes that are consistent with previous research (Frank, 2000; Frank et al., 2005). Comparing perceived micro built-environment to GIS-measured macro built-environment attributes, in our study, the correlations among perceived micro built-environment attributes are less strong. Moreover, GIS-measured macro built-environment attributes (except for neighbourhood land-use mix and – largely – social infrastructure intensity) are correlated with perceived micro built-environment attributes.

These correlations may influence relationships between neighbourhood built-environment attributes and the outdoor walking levels of survey participants. Findings of previous studies on significant relationships between outdoor walking levels of older adults and neighbourhood built-environment attributes in Birmingham, UK (Zandieh et al., 2016, 2017a) are presented in Table 5.8. Figure 5.5 uses these findings to show in visual form significant relationships between neighbourhood built-environment attributes and older adults' outdoor walking levels, as well as correlations among and between neighbourhood built-environment attributes.

Figure 5.5 includes all high, fair and weak correlations between built neighbourhood attributes. In Boxes A, B and C, each built-environment attribute is positively correlated with at least one built-environment attribute within the box (there are no negative correlations within these boxes). The dark boxes show older adults' outdoor walking levels and neighbourhood built-environment attributes that are significantly related to older adults' outdoor walking levels. Arrows show significant relationships and lines show correlations: '+' shows positive relationships/correlations and '-' shows negative relationships/correlations. GIS-measured land-use mix is related to outdoor walking levels only in areas where levels of deprivation are low (represented by a white box and a broken line/arrow).

Our study shows that neighbourhood built-environment attributes that are significantly related to outdoor walking levels of older adults – i.e. GIS-measured land-use intensity (green space, recreation centres, schools and industries) and street connectivity, and perceived safety, pedestrian infrastructure (quietness) and aesthetics – are correlated with each other (Table 5.7 and Figure 5.5) as

TABLE 5.8
Summary of Previous Studies in Birmingham (UK) on Relationships Between Outdoor Walking Levels of Older Adults and Neighbourhood Built-Environment Attributes (Data from Zandieh et al. 2016, 2017a)

Neighbourhood Built-Environment Attributes	Positive Relationship With Walking ^a	Negative Relationship With Walking ^b	No Relationship With Walking ^c
GIS-Measured Macro Built-Environment Attributes:			
Residential density			*
Land-use mix			* ^d
Land-use intensity			
Catering activities			*
Green space	*		
Recreation centres	*		
Social infrastructure			*
Retail activities			*
Schools		*	
Industries		*	
Street connectivity		*	
Retail density			*
Perceived Micro Built-Environment Attributes:			
Safety	*		
Pedestrian infrastructure			
Traffic condition			*
Pavement condition			*
Presence of amenities			*
Quietness	*		
Air quality			*
Aesthetics	*		
<i>Notes:</i> ^a Positive significant relationship between older adults’ outdoor walking levels and neighbourhood built-environment attribute, independent of area deprivation.			
^b Negative significant relationship between older adults’ outdoor walking levels and neighbourhood built-environment attribute, independent of area deprivation.			
^c No significant relationship between older adults’ outdoor walking levels and neighbourhood built-environment attribute.			
^d GIS-measured land-use mix is positively related to older adults’ outdoor walking levels only in areas where deprivation levels are low.			

well as with other neighbourhood built-environment attributes (Figure 5.5, Boxes B and C). These findings support previous studies that discuss relations between land use and safety (Stucky and Ottensmann, 2009), land use and noise (Sanz et al., 1993; Wolch et al., 2014), land use and aesthetics (Zhou and Parves Rana, 2012) and perceived safety and aesthetics (Loukaitou-Sideris, 2006). Negative correlations between GIS-measured street connectivity and perceived aesthetics may be explained by findings of previous studies: high levels of street connectivity may provide short, direct routes (Saelens et al., 2003b), but direct routes may offer walkers fewer ‘visual mysteries’ and have less visual appeal than curved streets (Nasar and Cubukcu, 2011).

Correlations among and between neighbourhood built-environment attributes may reinforce (or attenuate) the influence of other neighbourhood built-environment attributes on outdoor walking levels. For example, increasing positive aesthetic perceptions (by, for example, planting trees in streets) may attenuate the negative impacts of GIS-measured street connectivity on outdoor walking

FIGURE 5.5 Significant relationships between neighbourhood built-environment attributes and older adults' outdoor walking levels and correlations among and between neighbourhood built-environment attributes.

levels – owing to the negative correlation between perceived aesthetics and GIS-measured street connectivity. Similarly, improving positive perceptions of traffic conditions may attenuate negative relationship between GIS-measured land use (schools) intensity and older adults' outdoor walking levels – owing to negative correlations between perceived traffic conditions and GIS-measured school-use intensity. Therefore, most GIS-measured macro and perceived micro built-environment attributes are – significantly or indirectly (through another built environment attribute) – related to outdoor walking levels of older adults and have a synergy in creating a neighbourhood built-environment that supports outdoor walking among older adults.

These findings may help urban planners and policy-makers to prioritise their interventions. With the findings of our study in mind, a focus on modifying built-environment attributes significantly related to outdoor walking levels of older adults irrespective of their correlations with other neighbourhood built-environment attributes may not be the most effective strategy for supporting outdoor walking. Moreover, compared to macro built-environment attributes, generally micro built-environment attributes can be changed more rapidly and at less cost (Sallis et al., 2011). The findings of our study on correlations between GIS-measured macro built-environment attributes and perceived micro built-environment attributes may help urban planners (and other professionals) to reduce costs and speed up the implementations of actions for encouraging outdoor walking among older adults.

5.6 LIMITATIONS OF OUR STUDY

This study has some limitations, related to: using data from different years (i.e. 2001, 2012 and 2016); generating coarse data for residential and non-residential land use by assigning only one use to each building; defining a home-based neighbourhood for generating GIS-based macro built-environment attributes that is not necessarily the same as the perceived neighbourhood (of respondents) used for measuring perceived micro built-environment attributes; not showing causality between neighbourhood built-environment attributes; and focusing on one specific social group (in our case, older adults) in one city.

Moreover, this study examined correlations among perceived micro built-environment attributes. However, it is still unknown whether these correlations really exist among actual or GIS-measured

micro built-environment attributes. Future studies may have access to GIS-based data (for example, on air quality and noise) and include them in their research to measure GIS-measured micro built-environment attributes. In view of the unavailability of GIS-based data for some aspects of micro built-environment attributes (e.g. aesthetics), further efforts and studies are needed to produce that GIS-based data and to understand how to generate GIS-measured micro built-environment attributes.

Despite these limitations, this chapter provides an insight into the relationship between outdoor walking levels and neighbourhood built-environment attributes. In doing so, it also illustrates a GIS method that can be applied in studies on physical activities in other cities for which GIS-based data are available.

5.7 CONCLUSION

This chapter illustrates the capacity of GIS to contribute to urban planning studies on outdoor walking. GIS-based land use and transportation data were used to generate GIS-measures of one particular type of neighbourhood built-environment attributes: macro built-environment attributes. Subsequently, the GIS-measured macro built-environment attributes generated were used to examine correlations among those same neighbourhood macro built-environment attributes and between the macro and (perceived) micro built-environment attributes. Strong correlations were found among the GIS-measured macro built-environment attributes and also between GIS-measured macro and perceived micro built-environment attributes. Our study shows that most GIS-measured macro built-environment attributes are negatively correlated with perceived micro built-environment attributes. These correlations are likely to influence relationships between outdoor walking levels of older adults and neighbourhood built-environment attributes. The method we have illustrated and the results from the case study could well support the efforts of urban planners and policy-makers in prioritizing interventions, reducing costs and accelerating the implementation of actions to encourage outdoor physical activities, including walking levels of older adults.

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