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Neighbourhood design and identification of objective built environment features supportive of children's mental wellbeing

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ABSTRACT

Evidence is building to show that while individual characteristics are critical in determining health status, the built environment exacerbates or mitigates health outcomes, such as physical activity levels and mental illnesses. While there is ample research highlighting the role of built environment in encouraging physical activity, there is limited evidence on the association of children's local neighbourhoods and their mental wellbeing. This study investigates this link. A total of 163 children aged 9-12 years are recruited from four primary/secondary schools located in different neighbourhoods in Ankara, Turkey. Children's home-environments (400-meter radial buffers) are evaluated through GIS-based objective measures of land-use, urban densities, street connectivity and neighbourhood greenness index. Children's mental disorders and life satisfaction are evaluated through a combination of Me and My Feelings Survey and Students' Life Satisfaction Scale. Statistical analyses show that increased street connectivity around the home, measured by local syntactic measures, as well as higher neighbourhood land-use mix, and greenness are moderately but significantly associated with increased childhood mental health. The findings of this study enrich the limited knowledgebase on the environmental attributes associated with children's mental health and can inform practitioners with evidence-base when designing neighbourhoods supportive of increased mental wellbeing.

KEYWORDS

built environment, children's mental wellbeing, street connectivity, physical activity, Ankara-Turkey

1 INTRODUCTION

There is now a growing consensus that while individual factors are critical in shaping health, the urban environment exacerbates or mitigates health and wellbeing outcomes (Barton 2009). Extensive research indicates that neighbourhood design not only has direct impacts on individual health, including diabetes and obesity (Dendup et. al 2019), cardiovascular diseases (Nieuwenhuijsen 2018) and respiratory diseases (Song et. al 2014), but it also has indirect social and behavioural effects, such as on the levels of physical activity (PA) (Sallis et. al 2018). Evidence is building to show that PA is associated with reduced risks of mental illnesses such as depression, cognitive impairment, and dementia (Hamer and Chida 2008, Martinsen 2008) as well as emotional problems (Bell et. al 2019). Good neighbourhood design, which is a crucial determinant of active lifestyles, promotes increased PA necessary to reduce the burden of health conditions such as chronic depression, obesity, and cardio-vascular disease due to sedentary lifestyles. For example, a study has found a strong positive relationship between the local availability of shops and services and being able to walk easily to facilities and mental well-being (Calve-Blanco 2009).

Hence, understanding the interplay between children's local neighbourhood design and their mental wellbeing (including life satisfaction as well as emotional and behavioural difficulties) is of utmost importance since the findings can inform practitioners with evidence-base when designing neighbourhoods supportive of increased mental wellbeing.

2 THEORY

The impact of the built environment (BE) on PA and physical health among children and adolescents is well evidenced (Davison and Lawson 2006; Christian et. al 2015). Objective neighbourhood urban form features shown to promote an active lifestyle include higher residential/building density, diverse land-use, and well-connected street network, or the 3Ds (Cervero and Kockelman 1997, de Vries et. al 2007, Frank et. al 2007, van Loon et. al 2014), along with neighbourhood greenness (Tilt et. al 2007). Earlier studies concluded that safe and more densely built neighbourhoods, along with green space to be active in, facilitated healthy behaviours (i.e., active school travel, *AST*) promoting child health and development (Ding et. al 2011, Kyttä et. al 2012).

2.1 Density

Density is thought to influence PA by increasing opportunities that can be accessed on foot. More compact neighbourhoods could encourage active trips by reducing distance to destinations, such as schools. Many systematic reviews have reported a positive association between residential/urban density and PA (Sallis and Glanz 2006, van Loon et. al 2014), as well as active travel (Kyttä et. al 2012, Frank et. al 2007) and AST (D'Haese et. al 2015, Mitra 2013). However, the findings regarding the role of density in shaping PA are mixed. For example, while Ewing et al. (2004) did not find any association between population density within the home-environment and children's rates of

walking/cycling to school, Braza et al. (2004) identified a positive relationship between population density and rates of AST.

2.2 Land Use

Similar to density, land use diversity supports access to short-distance destinations and therefore is considered to be supportive of PA (Schicketanz et. al 2018). There is considerable evidence highlighting higher walking rates for transport and recreation among adults in neighbourhoods with increased number and variety of destinations (Transportation Research Board 2015, McCormack et. al 2007). Research on children and adolescents mirrors these findings, with land-use diversity shown to be significantly associated with park-based PA (Huang et al., 2020), recreational walking (Rosenberg et. al 2009) as well as walking to school (D'Haese et. al 2015, Pont et. al 2009). Furthermore, access to local destinations, such as neighbourhood recreation centres, has been positively associated with children's physical health and social competence (Christian et. al 2015). However, the empirical evidence on land use and children's PA and wellbeing is mixed, with some studies reporting either negative (Broberg and Sarjala 2015) or nonsignificant associations (Helbich 2018, Rothman et. al 2014). For example, Ozbil Torun et al. (2020) reported that the likelihood of walking for transportation purpose (including school trips) is higher when children live in neighbourhoods with increased commercial and recreational land uses, whereas extensive residential land use was found to discourage AST (Rothman et. al 2021). More specifically, land-use mix in school neighbourhoods may be positively related to AST, whereas diversity of land-uses in the home neighbourhood may not affect travel mode (Larsen et al., 2009). Therefore, there is lack of clear evidence on how the variety of land uses may support PA (Wong et. al 2011) and which land uses in particular may encourage increased PA among children.

2.3 Street Connectivity

In addition to density and land-use diversity, the way street network is designed was shown to affect people's travel behaviour. Earlier research demonstrated street connectivity (e.g., higher intersection density) to be associated with active living (Frank et. al 2007, van Loon et. al 2014). Street connectivity may result in closer trip destinations by providing relatively direct routes and therefore shorter distances. A well-connected street network may also create more opportunities to interact with a variety of destinations along a trip. Although there is a sizeable literature relating street network design and walking behaviour, in general, research investigating the associations of street network layout with children's PA and mental health is limited. While a number of studies found a positive association between children's PA/AST and street connectivity (Tewahade et. al 2019, Helbich et. al 2016, Ikeda et. al 2018), others have argued that a highly connected street network may also encourage increased car traffic (Giles-Corti et. al 2011, Bringolf-Isleret et. al 2010, Holtet et. al 2008, Spence et. al 2008), hence, discouraging active trips among children due to safety concerns.

The majority of previous studies employed standard measures of street connectivity, such as density of street intersections and block sizes, to measure street network design. However, these standard measures may not effectively capture the role of street connectivity in active travel since they don't fully capture the variations within the internal spatial structure of streets and neighbourhoods. Spatial structures may be defined as the way in which proximate road segments with different characteristics are laid together through certain hierarchies to create a network with systematic rather than statistically random properties of internal differentiation. Hence, syntactic measures have been developed within the framework of space syntax to evaluate the structural qualities of the urban grid (Hillier and Hanson). Studies employing syntactic measures have demonstrated a significant relationship between street connectivity and pedestrian movement (Koohsari et. al 2019, Baran et. al 2008). However, the use of these refined measures in studies of children's PA to date is limited (Ozbil et. al 2021, Cutumisu and Spence 2009).

2.4 Neighbourhood Greenness

Neighbourhood greenness also influences health and wellbeing (Hartig et. al 2014, Lachowycz and Jones 2013). The literature identified the direct and indirect effects of the quality of green spaces (Houlden et. al 2017), access and proximity to green spaces (Roe et. al 2020, Zhang et. al 2020); and the quantity of these spaces (Gascon et. al 2015, Gong et. al 2016) on people's mental health. Studies focussing specifically on children's and adolescents' mental health showed that while in early childhood more densely vegetated neighbourhoods are associated with increased outdoor playtime (Grigsby-Toussaint et. al 2011), among older children and adolescents increased green space accessibility (Wheeler et. al 2010) as well as larger proportion of neighbourhood green space are related to higher levels of PA (Almanza et. al 2012). In addition to PA, increased greenness was linked to positive emotional wellbeing (Huynh et. al 2013). An increase in neighbourhood vegetation, identified through the Normalized Difference Vegetation Index (NDVI), was shown to be associated with lower levels of depression and anxiety in children (Madzia et. al 2019).

2.5 Research Objectives

Although there is ample research highlighting the role of the built environment in encouraging increased PA among children, as discussed above, there is limited evidence on the association of children's local neighbourhoods and their mental wellbeing. Adopting a child-centred approach, this study aims to identify the extent to which neighbourhood design is associated with children's mental wellbeing, and hence contributes to the existing but limited body of work in this field. Another key research limitation in prior PA studies has been the lack of refined measures that capture the internal structure of urban areas. The significance of spatial structure in affecting pedestrian movement has been addressed through the framework of configurational analysis of space syntax (Ozbil et. al 2011, Baran et. al 2008); however, it has received little attention in the related literature. To overcome the limitations of standard connectivity measures used in PA studies, this research implements refined measures of spatial properties obtained from space syntax. Furthermore, the impact of the built

environment on children's mental wellbeing has been under-researched in Turkey, where increasing the quality of life of all segments of the population, including children, by promoting active living has become a national priority (Turkey Ministry of Health 2019). Understanding the link between the built environment and children's mental wellbeing in this region of the world is needed as increased physical inactivity and mental health problems among children and adolescents are presently displaying similar trends to those in developed countries.

3 DATASETS AND METHODS

3.1 Study Area Context

This study focuses on Ankara, Turkey, and its selected neighbourhoods. The city is the second largest in Turkey with an area of 24,521 km² and an estimated population of 5.6 million, approximately 287,000 of which are school year-aged children (<https://zhujiworld.com/tr/157408-ankara/>). The street network layout differs across the city, ranging from traditional grid-iron to cul-de-sac layout. Four neighbourhoods within the city were selected using the transect planning model proposed by Duany and Talen (2002). In this model, the rural to urban transect is divided into different zones determined by their urban form (e.g., street network design). Neighbourhoods with varying street typology (street connectivity assessed using syntactic measure of Integration¹) and neighbourhood greenness were targeted to explore how diverse neighbourhoods might have different influences on children's PA (i.e., children living in more walkable neighbourhoods with increased access to open/green spaces and a wide range of destinations versus those residing in car-oriented neighbourhoods with limited access to open/green spaces and destinations). Accordingly, Neighbourhood A is located in the 'urban core' with moderately high street connectivity and retail density as well as limited green space; Neighbourhood B belongs to 'general urban' category with relatively high land-use mix and street connectivity as well as limited green space; Neighbourhood C is a 'planned suburban' neighbourhood with a mixture of low- and high-rise buildings and relatively high land-use mix and street connectivity due to its planned grid-iron layout but with low retail density; Neighbourhood D is an unplanned, 'sprawling' neighbourhood with relatively more green space and decreased street connectivity and density, dominated by low-rise single multi-family and high-rise residential uses. Figure 1 demonstrates the case-study neighbourhoods.

¹ Integration calculates how close each street segment is to all the others within a set radius.

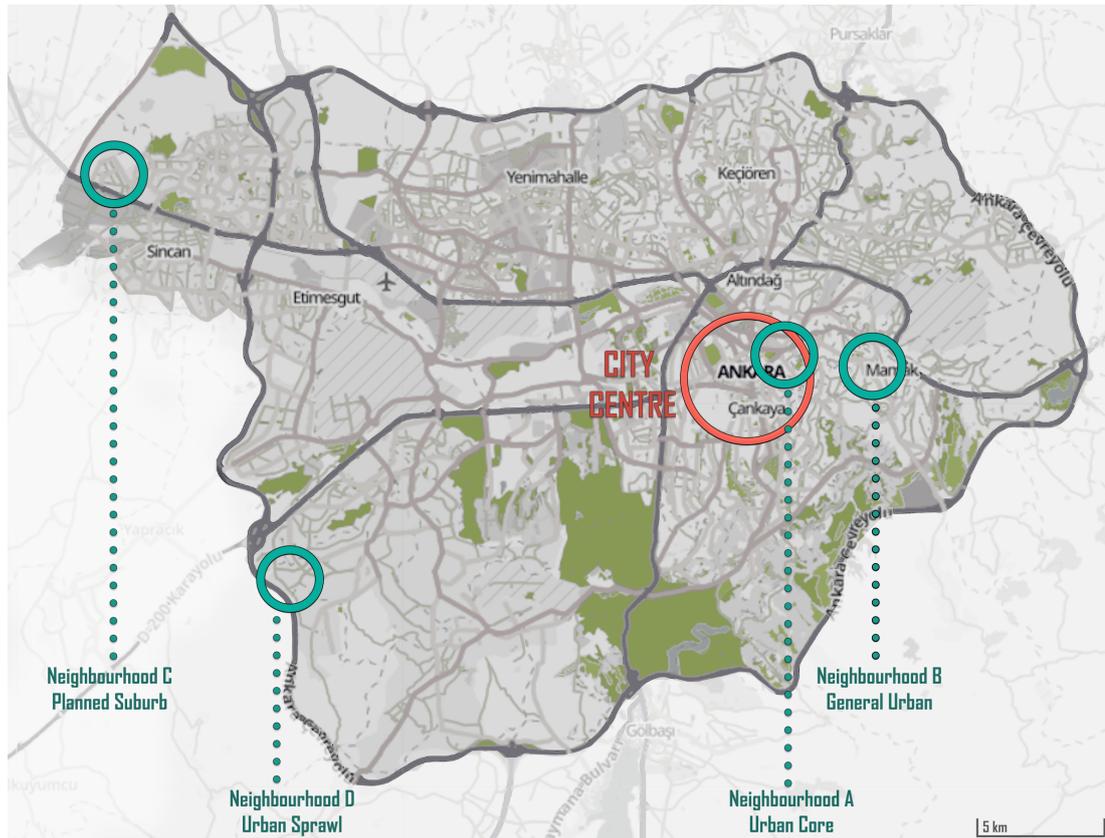


Figure 1: Case-study neighbourhoods demonstrated on the city map.

3.2 Sampling and Instrumentation

Children in middle-childhood (aged 9-12 years) were recruited for this study since this age group is beginning to travel independently to school, developing independent perceptions of influences on their routes to/from school. A total of 430 children (3rd-to-6th graders) were randomly selected from the primary and secondary schools located in the case-study neighbourhoods (~100 students per neighbourhood). The study protocol was approved by Ethics Commission, Middle East Technical University (Ethics ID: 053-ODTU-2021) and relevant permissions were granted by the Ankara Directorate of National Education (ID: E-14588481-605.99-22842379). A study information letter detailing the study procedure, accompanied with the parental survey and consent/assent forms, was sent to parents via students. Written informed consent/assent, from parent/guardian and child respectively, were obtained prior to the commencement of any data collection. Children's home postcodes and demographics (age, sex, parental education, etc.) were collected on the consent forms and the names of participants were coded to help maintain confidentiality.

Mental wellbeing and life satisfaction of participating children were evaluated through a combination of "Me and My Feelings Survey" (Deighton et al. 2013) and "Students' Life Satisfaction Scale" (Huebner 1991), both of which are validated measures of mental wellbeing. Me & My Feelings (M&MF) is a 16-item school-based measure of child mental health, covering emotional difficulties (first 10-items) and behavioural difficulties (last 6-items) on a 3-point Likert scale. Due to ethical



constraints imposed by the Ankara Directorate of National Education, items 13 (“I hit out when I am angry”), 14 (“I do things to hurt people”) and 16 (“I break things on purpose”) were omitted, resulting in 13-items overall. Combined with M&MF, “Students’ Life Satisfaction Scale”, a global 7-item measure to assess children’s and young people’s life satisfaction on a 6-point Likert scale, were also administered to participating children. Both measures are confirmed to be suitable for children and young people aged 8-18 (<https://www.corc.uk.net/outcome-experience-measures/students-life-satisfaction-scale-slss/>; <https://www.corc.uk.net/outcome-experience-measures/me-and-my-feelings-mmf/>). The combined survey was introduced to and filled by students in their classes where their class teachers were present.

The return rate of informed consent/assent was 57% and incomplete surveys (n = 78) were not included in further analyses. Therefore, the final student dataset included the answers of 163 students, of whom 37% were from the 3rd grade (approximately 9 years old) and 34% from 6th grade (approximately 12 years old).

3.3 Built Environment measures of home-neighbourhoods

Participating children’s home-environments (400meter radial buffers) were evaluated through four GIS-based objective measures of urban form thought to influence PA (Panter et. al 2008): land-use, urban densities, street network design and neighbourhood greenness index (Tilt et. al 2007). Similar to previous studies, a quarter-mile radial buffer (400m, or 5-minute walking distance) was created around homes using GIS to assess the more proximate home-neighbourhood around each child’s home (McMillan 2007, Kaczynski and Henderson 2007). All datasets were collected at the finest-resolution spatial units (i.e., land-use variables measured at the parcel-level while street connectivity measured at the segment-level).

Building density, parcel-level land-use mix and retail density as well as street connectivity and greenness index were summarized within each home-neighborhood area. Building density was defined as total built-up area (i.e., building footprint multiplied by the number of stories) per unit of home-neighbourhood area (Tsfazaki et. al 2010). Field audits were conducted to document land-use patterns within the home-neighborhoods as there is no valid parcel-based land-use data for Ankara. As in earlier research, parcel-based land-use mix was calculated based on eight categories of land-use (per building): institutional, educational, commercial, cultural, residential, mixed-use residential, mixed-use non-residential, and other (Frank et. al 2004); using the Equation below:

$$\text{land - use mix} = \frac{(-1) \times \left[\left(\frac{b1}{a} \right) \times \ln \left(\frac{b1}{a} \right) + \left(\frac{b2}{a} \right) \times \ln \left(\frac{b2}{a} \right) + \left(\frac{b3}{a} \right) \times \ln \left(\frac{b3}{a} \right) + \left(\frac{bn}{a} \right) \times \ln \left(\frac{bn}{a} \right) \right]}{\ln n}$$

where a= (total square meter of educational, commercial, residential, etc. buildings), b= (square meter of educational, commercial, residential, etc.). The entropy value ranges between 0 (perfectly homogenous land-use composition, wherein one single use dominates) and 1 (perfectly heterogeneous

land-use composition, with uses evenly spread among nine categories). In addition to land-use mix, retail density was calculated as ground floor retail land-use area divided by total land-use area within the buffers, based on Chen et al. (2012), to determine the ease of access to daily shopping within a participant's home-neighborhood.

Street network configuration of school-environments, defined as 3 km radial buffers around each school, was evaluated by using angular segment analysis measures of connectivity, Integration, Choice, and normalised Choice (NACH), implemented in Depthmap (Turner and Friedrich 2010). In line with past research, this buffer was selected to avoid an "edge effect" in the calculation of the syntactic measures as well as to allow for the analysis of most of the pedestrian movement (Hillier and Iida 2005, Summers and Johnson 2017). While connectivity calculates the number of immediate segments that are directly connected to each street segment space, Integration is a relativized measure of the topological distance of segments in a street network (Hillier and Hanson 1984). Normalised angular Choice measures the extent to which a specific street segment lies along the shortest path between any pairs of segments in a network by taking into account the depth of the segment in the system (Hillier et. al 2012). These syntactic measures are calculated based on topological, or step distance, rather than metric distance that is widely accepted in the related literature. In line with most previous space syntax studies, all syntactic measures were computed locally and globally since it is argued that they represent different levels of movement potentiality. Integration and Choice/Normalised Choice were calculated for radius n (global) and 3 (local) as well as 400m (local).

In addition to these three urban form measures, a greenness index, or Normalized Difference Vegetation Index (NDVI), which is a remotely sensed vegetation index derived from satellite sensors, was calculated within each home-neighborhood using ArcGIS 10.8.1. Relevant dataset was acquired from Landsat 8 on May 28, 2021, when the cloud coverage was less than 10%, and NDVI was calculated as $(\text{near infrared} - \text{red}) / (\text{near infrared} + \text{red})$ (Shankhwar et. al 2021). The index ranges from -1 to 1, with more positive values indicating increased greenness, and thus more vegetation, in the pixel (Tilt et. al 2007). Table 1 summarizes the measures used in this study.



Table 1: Measures used in this study.

Measure	Description	Unit of Measurement
Building density	Total built-up area (i.e., building footprint multiplied by the number of stories) per unit of home-neighbourhood area	Continuous variable (in mt ²)
Land-use mix	Evenness of distribution of institutional, educational, commercial, residential, mixed-use residential, mixed-use, assembly, vacant and other per unit of land area	0 to 1
Retail density	Ground floor retail land-use area divided by total land-use area	Continuous variable (in mt ²)
Greenness Index (NDVI)	The ratio of the difference between near infrared (NIR) and red (R) reflectance to their sum	-1 to 1
Street connectivity		
Connectivity	local measure	Continuous variable
Integration (global)	r:n	Continuous variable
Integration (local)	r:3, 400m	Continuous variable
Normalised Angular Choice (NACH) (global)	r:n	Continuous variable
Normalised Angular Choice (NACH) (local)	r:400m	Continuous variable
Choice (local)	r:3, 400m	Continuous variable

3.4 Children’s mental wellbeing

The total score for Me & My Feelings (M&MF) was calculated by adding all 13 items in the scale. Rating responses for this scale were scored as follows: Never = 0, Sometimes = 1, Always = 2; while item 15 (“I am calm”) was reverse scored. To calculate the subscale scores, the first 10 items and items 11-13 were added separately. The first represents the Emotional Difficulties subscale while the latter comprises the Behavioural Difficulties subscale. Hence, the total score for the Emotional Difficulties subscale is 20, and is 6 for the Behavioural Difficulties subscale, giving an overall total score of 26 (a higher score indicating more problems). Cut-off scores with clinical significance, based on Deighton et al. (2013), were established resulting in a score of 10 and above indicating problems on the emotional difficulties scale (≤ 9 expected, 10–11 borderline, ≥ 12 clinical), and scores ≥ 4 indicating behavioural problems on the behavioural difficulties scale (≤ 2 expected, 3 borderline, ≥ 4 clinical).

Items in “Students’ Life Satisfaction Scale” were scored on a scale from 1 (strongly disagree) to 6 (strongly agree), except for the two items “I would like to change many things in my life” and “I wish I had a different kind of life” where responses were reverse-scored from 6 to 1. A total score for each child was calculated by averaging the scores for the 7 items. A higher score was indicative of more mental health disorder symptoms.

3.5 Analysis

First, to indicate the factors potentially affecting children’s mental wellbeing, statistical significance of dependent and independent variables across selected neighborhoods was computed using one-way ANOVA analysis. The one-way ANOVA results identify whether the average values of each BE

attribute are significantly different for each neighborhood type. A BE attribute with a relatively large difference and statistical significance (at the 95% and 90% confidence interval) indicates that it could be a partial underlying reason of children's mental wellbeing. Next, to avoid multicollinearity effect, a correlation analysis among the 12 explanatory factors was conducted and variables with stronger correlations (> 0.7) were not considered for further analysis. 2 variables excluded based on this analysis were global Integration (r:n) and global NACH (r:n). Finally, the effects of different BE variables on children's mental wellbeing were estimated in multinomial logistic regression models (for categorical emotional/behavioral difficulty outcomes) and multivariate regression models (for continuous life satisfaction outcome) separately to assess the main effects of the BE variables on children's mental health. A control variable -child's age- was also included. All statistical analyses were conducted in SPSS (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp).

4 RESULTS

4.1 Descriptive Information

Table 2 summarizes the proportions (for categorical measures) or means and standard deviations (for continuous measures) of all variables in the final sample along with their statistical significance across selected neighbourhoods. Of the 163 participants, aged 9-12 years, 75% of participants reported expected emotional difficulties while 66% reported expected behavioural difficulties.

Based on the information presented in Table 2, the average Student's Life Satisfaction was 4.18 for children in the final sample, while 25% of children had borderline and/or clinically significant emotional difficulties and 34% of children had borderline and/or clinically significant behavioural difficulties. The average life satisfaction and behavioural difficulties of children varied by neighbourhood. Children living in Neighbourhood D (urban sprawl) had less emotional difficulties in comparison to children from other neighbourhoods while children residing in Neighbourhood C (planned suburban) had the most behavioural difficulties across the sample. To be specific, children with expected emotional difficulties living in urban core, general urban, suburban and sprawling neighbourhoods were 72%, 75%, 67% and 86%, respectively, while their corresponding expected behavioural difficulties were 78%, 65%, 55%, and 79%. In contrast, children living in urban core had the highest average life satisfaction score in comparison to their peers residing in other neighbourhoods. More precisely, average Student's Life Satisfaction for children living in Neighbourhoods A, B, C, and D was 4.44, 4.28, 3.92, and 4.31, respectively. One-way ANOVA statistics further confirmed significant differences in children's mental wellbeing and life satisfaction across home-neighbourhoods. Although no statistically significant difference was observed in children's emotional difficulties across the neighbourhoods, one-way ANOVA results confirmed a significant relationship between neighbourhood type and behavioural difficulties ($p < .04$). In addition, one-way ANOVA results indicated that average student's life satisfaction was significantly different across the neighbourhoods ($p < .07$).

Table 2: Means (and standard deviations) of dependant and independent variables by school/neighbourhood.

	Full (n=163)	Neighbour. A (n=18) urban core	Neighbour. B (n=48) general urban	Neighbour. C (n=55) planned suburban	Neighbour. D (n=42) sprawling	p value
Child's Mental Wellbeing						
Emotional difficulties [†]	75%	72%	75%	67%	86%	
Behavioural difficulties [†]	66%	78%	65%	55%	79%	**
Life Satisfaction	4.18 (0.94)	4.44 (1.05)	4.28 (0.86)	3.92 (1.00)	4.31 (0.84)	*
Home-Neighbourhood Built Environment						
Building density	1106.15 (522.05)	1365.51 (307.26)	1749.80 (154.17)	652.19 (241.53)	853.87 (278.30)	***
Land-use mix	.37 (.14)	.18 (.08)	.40 (.05)	.44 (.14)	.33 (.13)	***
Retail density	.21 (.13)	.45 (.11)	.29 (.04)	.12 (.08)	.12 (.08)	***
NDVI	.13 (.04)	.14 (.02)	.09 (.01)	.12 (.02)	.18 (.01)	***
Home-Environment Street connectivity						
avg. Connectivity	3.36 (.38)	3.83 (0.22)	3.14 (.25)	3.11 (.11)	3.75 (.24)	***
avg. NACH (r:400m)	1.08 (.08)	1.04 (.02)	1.16 (.04)	1.11 (.03)	0.98 (.04)	***
avg. Choice (r:400m)	963.67 (764.71)	231.91 (37.33)	948.69 (224.33)	1845.29 (458.48)	139.91 (48.15)	***
Avg. Choice (r:3)	5721.68 (4045.68)	2503.17 (1003.76)	4208.77 (834.19)	10620.46 (3008.85)	2415.02 (954.83)	***
avg. Integration (r:400m)	60.57 (26.65)	35.75 (1.96)	67.48 (6.88)	88.14 (13.63)	27.22 (4.37)	***
Integration (r:3)	445.33 (441.06)	114.30 (27.41)	1120.73 (14.83)	223.30 (32.36)	106.04 (22.45)	***

Note: *p < .1, **p < .05, ***p < .01

[†] (expected=0, borderline=1, clinically significant=2); %s reported depict expected category.

Home-environment built environment also varied by neighbourhood. One-way ANOVA tests confirmed the statistically significant relationship between home-environment built environment and neighbourhood type. Table 2 shows that a significant difference exists between the case-study neighbourhoods for all BE attributes, suggesting that these BE features might be partial underlying reasons for children's mental wellbeing. The independent effects of these features are analysed in multinomial logistic and multivariate regression models in the following section.

4.2 Built environment attributes associated with mental wellbeing

Tables 3 and 4 present the results from multinomial logistic regression models of children's mental wellbeing. The control variable included in the study was significantly related to children's behavioural difficulties. In other words, older children were more likely to have borderline behavioural difficulties, compared to their younger peers. For the full sample, the increased land-use mix ($B = -4.87, p < .05$) and NDVI ($B = -59.81, p < .01$) in the home-environment were associated with decreased risk of emotional difficulties among children (Table 3). The odds of having clinically

significant emotional difficulties (vs expected) decreased by a factor of 0.01 ($p < 0.05$) for every additional unit of land-use mix per parcel around the home and by a factor of 0.03 ($p < .01$) for every additional unit of NDVI in the home-neighbourhood. The models also highlight that street connectivity in children's home-environment was also significantly related to their mental health status through its impacts on behavioural difficulties (Table 4). Increased Integration (r:400m) was associated with reduced emotional difficulties (clinically significant difficulty vs expected), albeit marginally (OR=.88), whereas increased street connectivity and NACH (r:400m) were associated with reduced behavioural difficulties (borderline difficulty vs expected; ORs=.07 and .01). Other objective BE variables appeared to be statistically insignificant in the model estimating behavioural difficulties.

Table 3: Multivariate relations of BE variables to children's emotional difficulties (N=163).

	Borderline (vs expected)		Clinically significant (vs expected)	
	B	OR (95 % CI)	B	OR (95 % CI)
Child age	-.90	.91 (.33-2.51)	.08	1.08 (.39-2.97)
Building density	-0.00	1.00 (1.00-1.00)	-.00	1.00 (1.00-1.00)
Land-use mix	-1.00	.38 (.01-27.56)	-4.87**	.01 (.00-1.0)**
Retail density	.98	2.66 (.002-371.88)	.08	1.08 (.00-1318.57)
NDVI	-18.34	.02 (.00-256.34)	-59.81***	.03 (.00-123.45)***
Connectivity	1.94	.696 (.39-125.46)	.62	1.86 (.12-28.49)
Choice (r:400m)	.00	1.00 (1.00-1.01)	-.00	1.00 (1.00-1.01)
Integration (r:400m)	.02	1.02 (.09-1.18)	-.12*	.88 (.74-1.06)*

Note: All variables were grand mean centred.

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 4: Multivariate relations of BE variables to children's behavioural difficulties (N=163).

	Borderline (vs expected)		Clinically significant (vs expected)	
	B	OR (95 % CI)	B	OR (95 % CI)
Child age	.82*	2.26 (.91-5.63)*	.39	1.48 (.56-3.92)
Building density	.00	1.00 (1.00-1.00)	-.002	1.00 (1.00-1.00)
Land-use mix	.93	2.53 (.06-105.68)	1.39	4.02 (.07-222.76)
Retail density	-.06	.94 (.005-167.88)	1.6	4.95 (.04-613.05)
NDVI	10.00	21.34 (15.53-425.56)	1.39	4.02 (.07-222.76)
Connectivity	-2.63**	.07 (.008-.67)**	1.31	3.70 (.20-68.99)
NACH (r:400m)	-14.87*	.01(.00-5.83)*	-1.68	.19 (.00-18.93)
Integration (r:400m)	.02	1.03 (.98-1.08)	.02	1.02 (.97-1.01)

Note: All variables were grand mean centred.

* $p < .1$, ** $p < .05$, *** $p < .01$

The estimated coefficients of the variables, standard errors, and standard B statistics, with the corresponding significance levels, for the multivariate regression estimating the variance in average life satisfaction scores are reported in Table 5. The neighbourhood type was included as a fixed variable in the model to capture the effects of different neighbourhoods on the child's life satisfaction. Child's age was significantly related to the average life satisfaction score among children, with younger children having higher life satisfaction. Regarding the objective built environment attributes, increased land-use mix (std B = .27, $p < .08$) around the home was significantly related to increased life satisfaction among the children, albeit marginally. NDVI, retail density and building density within the home-neighbourhood did not appear to be significant BE variables in explaining students' life satisfaction status. Results indicate that street connectivity was significantly associated with the outcome variable. Notably, the syntactic measures, average connectivity (std B = .33, $p < .05$) and local choice (std B = .46, $p < .08$) showed modest associations with student's life satisfaction. We can infer that children living in neighbourhoods with increased number of street connections and directional accessibility within their immediate surroundings were more likely to have increased life satisfaction, compared to their peers living in neighbourhoods with less connected street networks. Surprisingly, local integration (r:3) (std B = -7.27 , $p < .01$) was negatively correlated with children's life satisfaction. This may be due to the increasing levels of automobile traffic associated with better integrated streets with their surroundings, which can discourage and prevent PA (Mecredy et. al 2011, Tappe et. al 2013) among children due to safety concerns. More specifically, children living in general urban neighbourhoods (std B = 9.39, $p < .01$) had increased life satisfaction while those residing in the urban core and/or planned suburbs (std B = -2.14 , $p < .05$; std B = -2.30 , $p < .05$, respectively) had reduced life satisfaction, when compared to their peers living in sprawling neighbourhoods.

Table 5: Multivariate relations of BE variables to children's average life satisfaction (N=163).

	Outcome variable: children's average life satisfaction		
	B	std B	std error
Child age	-.49*	-.67*	.28*
Building density	-.00	-.10	.00
Land-use mix	1.88	.27*	1.10*
Retail density	-2.12	-.30	1.47
NDVI	7.54	.31	8.59
Connectivity	.83**	.33**	.42**
Choice (local, r:3)	.00*	.46*	.00*
Integration (local, r:3)	-.02***	-7.27***	.01***
Neighbourhood (urban core)	-3.44**	-2.14**	1.52**
Neighbourhood (general urban)	11.83***	9.39***	4.47***
Neighbourhood (planned suburban)	-2.80**	-2.30**	1.38**

Note: Neighbourhood type was used as a fixed effect. reference category was Neighbourhood D (urban sprawling).

* $p < .1$, ** $p < .05$, *** $p < .01$

5 CONCLUSIONS

This study further evaluated the associations of children's mental wellbeing and life satisfaction with some specific BE attributes in home-environments (i.e., 400m buffers) among a cohort of 163 children aged 9-12 years in Turkey. By analysing the objectively measured BE features, including street connectivity measures from space syntax, this study provided important new insights into their effect on children's mental health.

The results from multinomial logistic regression and multivariate regression models showed that built environment in neighbourhood was significantly related to children's mental health status. More importantly, this study emphasizes the significance of spatial structure of street network around the home in affecting children's mental health. The local syntactic measures Integration, Choice/normalised Choice, and connectivity were moderately but consistently correlated with children's emotional and behavioural difficulties as well as life satisfaction. As indicated by our statistical analyses results, increased directional accessibility (i.e., more direct routes) was associated with reduced emotional and behavioural difficulties as well as increased life satisfaction among the children. From a design policy point of view, designing better connected street networks (e.g., integrated within their surroundings) with increased number of connections and reduced directional distance between home and school can support children's mental health and life satisfaction by mitigating emotional or behavioural difficulties. Thus, retrofitting neighbourhood design to promote connectivity has strong potential to support mental wellbeing of children by way of promoting their PA levels. This finding contributes to the limited evidence on the relationship between street network design and mental wellbeing, and contrasts with an earlier study, which found no association of street connectivity with mental health among adults (Melis et. al 2015).

Although previous studies have reported mixed results regarding the association between BE attributes and children's mental wellbeing (Broberg and Sarjala 2015, Helbich 2018), the associations found in this study suggest that land-use mix and green space exposure (i.e., NDVI) were both associated with children's mental health status even after controlling for building and retail density. Results suggest that increased land-use mix within a 5-minute walking range of homes is related to reduced emotional difficulties while increased amount of "greenness" (e.g., trees and vegetation) around the home is associated with increased life satisfaction among children. These results are similar to that of Leslie and Cerin (2008) and suggest that greater land-use mix and green space around the home may be markers of walkable environments, such as pedestrian-oriented design and a safer social environment, thus supporting increased PA and reduced risk of mental illnesses. Thus, land-use mix and access and proximity to green spaces should be considered in neighbourhood redevelopment practices. However, findings that retail and building density within the home-environment were not associated with children's mental health status suggest that additional research is needed to clarify the role of urban densities before recommendations can be made.

There are several limitations of this study. First, the study data is cross-sectional, which inhibits the specification of any causal relationship between the specific built environment attributes and



children's mental health status. Since mental health disorders may be developed over an extended period (Zimmerman et. al 2000), future research should implement multilevel statistical models and longitudinal analysis to shed more light on the influences of neighbourhood built environment on children's mental wellbeing. Second, the BE measures used to assess children's neighbourhoods in this paper are limited. The study only identified the presence of specific BE attributes in the neighbourhood, not including other factors, such as the quality or children's perceptions of these environments, that might significantly impact children's mental wellbeing. Utilizing such data, as recommended by scholars (Sallis et. al 2012), may lead to stronger associations with environmental attributes. In addition, control variables, such as individual and household characteristics, were not accounted for (except for child's age) due to the lack of such data at present. The results reported here are part of an ongoing research; hence, future work will control for these variables to lead to a more comprehensive understanding of factors at play. Finally, although our case-study areas are representative of diverse urban areas, including suburban and urban core, these environments are arguably more walkable as compared to their rural counterparts. Thus, further research that includes both urban and rural study sites is needed to test the generalizability of the results reported here.

Despite these limitations, findings from this study consolidate the argument that children's mental wellbeing can be supported by modifying the built environment within the home-neighbourhood to improve public health and mitigate direct and indirect costs for economies and communities (Cummins and Jackson 2001). As recent years witnessed growing investigations into the health impacts of socio-ecological determinants, this study enriches the limited knowledgebase of socio-ecological model of childhood mental health by specifically focusing on objectively measured BE attributes of the residential neighbourhood. This study empirically demonstrated significant associations between specific BE attributes in the local neighbourhood and mental health and wellbeing in children.

Identifying the extent to which specific built environment features around the home are related to children's mental health may also inform urban planners, designers, and health professionals on how to develop and implement more effective behaviour change interventions at the neighbourhood level. Understanding the nature of such associations will add context and value when designing neighbourhoods around schools that would support a re-thinking and re-designing of streets and public spaces that enable physically and socially active children and communities, which in turn improve human health.

Acknowledgements: This work was supported by the British Academy (BA) Humanities and Social Sciences Tackling Global Challenges Programme 2020, grant number TGC\200140. The authors thank all children and parents who took part in this study and Derya Karadak, Ezgi Turgut and Berk Gok for assisting with data collection.



REFERENCES

- Almanza, E., Jerrett, M., Dunton, G., Seto, E. and Ann Pentz, M. (2012) 'A study of community design, greenness, and physical activity in children using satellite, GPS and accelerometer data', *Health & Place*, 18(1), pp. 46-54.
- Baran, P., Rodríguez, D. and Khattak, A. (2008) 'Space Syntax and Walking in a New Urbanist and Suburban Neighbourhoods', *Journal of Urban Design*, 13(1), pp. 5-28.
- Barton, H. (2009) 'Land use planning and health and well-being', *Land use policy*, 26(1), pp. 115-123.
- Bell, S. L., Audrey, S., Gunnell, D., Cooper, A. and Campbell, R. (2019) 'The relationship between physical activity, mental wellbeing and symptoms of mental health disorder in adolescents: a cohort study', *International Journal of Behavioural Nutrition and Physical Activity*, 16(1), pp. 1-12.
- Braza, M., Shoemaker, W. and Seeley, A. (2004) 'Neighborhood design and rates of walking and biking to elementary school in 34 California communities', *American Journal of Health Promotion*, 19(2), pp. 128-136.
- Broberg, A. and Sarjala, S. (2015). 'School travel mode choice and the characteristics of the urban built environment: the case of Helsinki, Finland', *Transport policy*, 37, pp.1-10.
- Calve-Blanco, T. (2009) 'Mental well-being, social capital and neighbourhood form unpublished PhD draft, WHO Collaborating Centre for healthy urban environments, University of the West of England, Bristol.
- Cervero, R. and Kockelman, K. (1997) 'Travel Demand and the 3DS: Density, Diversity, and Design', *Transportation Research Part D: Transport and Environment*, 2(3), pp. 199-219.
- Chen, L., Chen, C., Srinivasan, R., McKnight, C., Ewing, R. and Roe, M. (2012) 'Evaluating the Safety Effects of Bicycle Lanes in New York City', *American Journal of Public Health*, 102(6), pp. 1120-1127.
- Christian, H., Zubrick, S. R., Foster, S., Giles-Corti, B., Bull, F., Wood, L., Knuiman, M., Brinkman, S., Houghton, S. and Boruff, B. (2015) 'The influence of the neighborhood physical environment on early child health and development: A review and call for research', *Health Place*, 33, pp. 25-36.
- Cohen, W. and Goward, S. (2004) 'Landsat's Role in Ecological Applications of Remote Sensing', *BioScience*, 54(6), pp. 535-545.
- Cummins, S. and Jackson, R. (2001) 'The Built Environment and Children's Health', *Pediatric Clinics of North America*, 48(5), pp. 1241-1252.
- Cutumisu, N. and Spence, J. (2009) 'Exploring associations between urban environments and children's physical activity: Making the case for space syntax', *Journal of Science and Medicine in Sport*, 12(5), pp. 537-538.
- Davison, K. K. and Lawson, C. T. (2006) 'Do attributes in the physical environment influence children's physical activity? A review of the literature', *International Journal of Behavioral Nutrition and Physical Activity*, 3(1), pp. 1-17.
- Deighton, J., Tymms, P., Vostanis, P., Belsky, J., Fonagy, P., Brown, A., Martin, A., Patalay, P. and Wolpert, M. (2013) 'The Development of a School-Based Measure of Child Mental Health', *Journal of Psychoeducational Assessment*, 31(3), p. 247.
- Dendup, T., Astell-Burt, T. and Feng, X. (2019) 'Residential self-selection, perceived built environment and Type 2 diabetes incidence: A longitudinal analysis of 36,224 middle to older age adults', *Health Place*, 58, 102154. doi: 10.1016/j.healthplace.2019.102154.
- De Vries, S.I., Bakker, I., Van Mechelen, W. and Hopman-Rock, M. (2007) 'Determinants of activity-friendly neighborhoods for children: Results from the SPACE study', *American Journal of Health Promotion: AJHP*, 21(4 Suppl), pp. 312-316.
- D'Haese, S., Vanwolleghem, G., Hinckson, E., de Bourdeaudhuij, I., Deforche, B., Van Dyck, D. and Cardon, G. (2015) 'Cross-continental comparison of the association between the physical environment and active transportation in children: a systematic review', *International Journal of Behavioural Nutrition and Physical Activity*, 12(1), pp. 1-14.



- Ding, D., Sallis, J.F., Kerr, J., Lee, S. and Rosenberg, D.E. (2011) 'Neighborhood environment and physical activity among youth a review', *American Journal of Preventive Medicine*, 41(4), pp. 442-455.
- Duany, A. and Talen, E. (2002) 'Transect Planning' *Journal of the American Planning Association*, 68(3), p.245.
- Ewing, R., Schroeder, W. and Greene, W. (2004) 'School location and student travel', *Transportation Research Record*, 1895(1), pp. 55-63.
- Frank, L., Andresen, M. and Schmid, T. (2004) 'Obesity relationships with community design, physical activity, and time spent in cars' *American Journal of Preventive Medicine*, 27(2), pp. 87-96. doi: 10.1016/j.amepre.2004.04.011
- Frank, L., Kerr, J., Chapman, J. and Sallis J. (2007) 'Urban form relationships with walk trip frequency and distance among youth', *American Journal of Health Promotion*, 21(4) p. 305-311.
- Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Forn, J., Plasència, A. and Nieuwenhuijsen, M. (2015) 'Mental Health Benefits of Long-Term Exposure to Residential Green and Blue Spaces: A Systematic Review', *International Journal of Environmental Research and Public Health*, 12(4), pp. 4354-4379.
- Gong, F., Zheng, Z.C. and Ng, E. (2016) 'Modeling elderly accessibility to urban green space in high density cities: A case study of Hong Kong', *Procedia Environmental Sciences*, 36, pp. 90-97.
- Grigsby-Toussaint, D., Chi, S. and Fiese, B. (2011) 'Where they live, how they play: Neighborhood greenness and outdoor physical activity among preschoolers', *International Journal of Health Geographics*, 10(1), pp. 10-66.
- Hamer, M. and Chida, Y. (2008) 'Active commuting and cardiovascular risk: a meta-analytic review', *Preventive medicine*, 46(1), pp. 9-13.
- Hartig, T., Mitchell, R., De Vries, S. and Frumkin, H. (2014) 'Nature and Health', *Annual Review of Public Health*, 35(1), pp. 207-228.
- Helbich, M. (2018) 'Toward dynamic urban environmental exposure assessments in mental health research', *Environmental research*, 161, pp.129-135.
- Hillier, B. (1999) 'The Need for Domain Theories', *Environment and Planning B: Planning and Design*, 26(2), pp. 163–167. doi: 10.1068/b2602ed.
- Hillier, B. (2012) 'Studying Cities to Learn about Minds: Some Possible Implications of Space Syntax for Spatial Cognition', *Environment and Planning B: Planning and Design*, 39(1), pp. 12–32. doi: 10.1068/b34047t.
- Hillier, B., & Hanson, J. (1984). *The social logic of space*. Cambridge [Cambridgeshire], Cambridge University Press.
- Hillier, B. and Sahbaz, O. (2005) 'High resolution analysis of crime patterns in urban street networks: an initial statistical sketch from an ongoing study of a London borough', In: *van Nes A (ed) Proceedings of the fifth international space syntax symposium*. Delft: Delft University of Technology.
- Hillier, W. R. G., Yang, T. and Turner, A. (2012) 'Normalising least angle choice in Depthmap-and how it opens up new perspectives on the global and local analysis of city space' *Journal of Space syntax*, 3(2), pp. 155-193.
- Houlden, V., Weich, S. and Jarvis, S. (2017) 'A cross-sectional analysis of green space prevalence and mental wellbeing in England', *BMC Public Health*, 17(1), pp. 1-9.
- Huang, J., Hipp, J., Marquet, O., Alberico, C., Fry, D., Mazak, E., Lovasi, G., Robinson, W. and Floyd, M.F. (2020) 'Neighborhood characteristics associated with park use and park-based physical activity among children in low-income diverse neighborhoods in New York City', *Preventive Medicine*, 131, p. 105948.
- Huebner, E., (1991) 'Further Validation of the Students' Life Satisfaction Scale: The Independence of Satisfaction and Affect Ratings', *Journal of Psychoeducational Assessment*, 9(4), pp. 363-368.



- Huynh, Q., Craig, W., Janssen, I. and Pickett, W. (2013) 'Exposure to public natural space as a protective factor for emotional well-being among young people in Canada', *BMC Public Health*, 13(1), pp. 1-14.
- Kaczynski, A. and Henderson, K. (2007) 'Environmental Correlates of Physical Activity: A Review of Evidence about Parks and Recreation', *Leisure Sciences*, 29(4), pp. 315-354.
- Koohsari, M., Oka, K., Owen, N. and Sugiyama, T. (2019) 'Natural movement: A space syntax theory linking urban form and function with walking for transport', *Health & Place*, 58, p. 102072.
- Kyttä, A. M., Broberg, A. K. and Kahila, M. H. (2012) 'Urban environment and children's active lifestyle: SoftGIS revealing children's behavioral patterns and meaningful places', *American Journal of Health Promotion*, 26(5), pp. 137-148.
- Lachowycz, K. and Jones, A. (2013) 'Towards a better understanding of the relationship between greenspace and health: Development of a theoretical framework', *Landscape and Urban Planning*, 118, pp. 62-69.
- Leslie, E. and Cerin, E. (2008) 'Are perceptions of the local environment related to neighbourhood satisfaction and mental health in adults?', *Preventive Medicine*, 47(3), pp. 273-278.
- Madzia, J., Ryan, P., Yolton, K., Percy, Z., Newman, N., LeMasters, G. and Brokamp, C. (2019) 'Residential greenspace association with childhood behavioral outcomes', *The Journal of pediatrics*, 207, pp. 233-240.
- Martinsen, E. W. (2008) 'Physical activity in the prevention and treatment of anxiety and depression', *Nordic journal of psychiatry*, 62(sup47), pp. 25-29.
- McCormack, G.R., Giles-Corti, B. and Bulsara, M. (2007) 'Correlates of using neighborhood recreational destinations in physically active respondents', *J Phys Act Health*, 4(1), pp. 39-53.
- McMillan, T. (2007) 'The relative influence of urban form on a child's travel mode to school', *Transportation Research Part A: Policy and Practice*, 41(1), pp. 69-79.
- Mecredy, G., Janssen, I. and Pickett, W. (2011) 'Neighbourhood street connectivity and injury in youth: a national study of built environments in Canada', *Injury Prevention*, 18(2), pp. 81-87.
- Melis, G., Gelormino, E., Marra, G., Ferracin, E. and Costa, G. (2015) 'The Effects of the Urban Built Environment on Mental Health: A Cohort Study in a Large Northern Italian City', *International Journal of Environmental Research and Public Health*, 12(11), pp. 14898-14915.
- Mitra, R. (2013) 'Independent mobility and mode choice for school transportation: a review and framework for future research', *Transport Reviews*, 33(1), pp. 21-43.
- Nieuwenhuijsen, M.J. (2018) 'Influence of urban and transport planning and the city environment on cardiovascular disease', *Nat. Rev. Cardiol*, 15(7), pp. 432-438. doi: 10.1038/s41569-018-0003-2
- Ozbil, A., Peponis, J. and Stone, B. (2011) 'Understanding the link between street connectivity, land use and pedestrian flows', *URBAN DESIGN International*, 16(2), pp. 125-141.
- Ozbil, A., Yesiltepe, D., Argin, G. and Rybarczyk, G. (2021) 'Children's Active School Travel: Examining the Combined Perceived and Objective Built-Environment Factors from Space Syntax', *International Journal of Environmental Research and Public Health*, 18(1), p. 286.
- Panter, J., Jones, A. and Van Sluijs, E. (2008) 'Environmental determinants of active travel in youth: A review and framework for future research', *International Journal of Behavioral Nutrition and Physical Activity*, 5(1), pp. 1-14.
- Roe, J. (2016) 'Cities, green space, and mental well-being', In: *Oxford research encyclopedia of environmental science*.
- Rosenberg, D., Ding, D., Sallis, J. F., Kerr, J., Norman, G. J., Durant, N., Harris, S. K. and Saelens, B. E. (2009) 'Neighborhood Environment Walkability Scale for Youth (NEWS-Y): reliability and relationship with physical activity', *Preventive Medicine*, 49(2-3), pp. 213-218.
- Rothman, L., Hagel, B., Howard, A., Cloutier, M., Macpherson, A., Aguirre, A., McCormack, G., Fuselli, P., Buliung, R., HubkaRao, T., Ling, R., Zanotto, M., Rancourt, M. and Winters, M. (2021) 'Active school transportation and the built environment across Canadian cities: Findings from the

child active transportation safety and the environment (CHASE) study', *Preventive Medicine*, 146, p. 106470.

Sallis, J.F., Conway, T.L., Cain, K.L., Carlson, J.A., Frank, L.D., Kerr, J., Glanz, K., Chapman, J.E. and Saelens, B.E. (2018) 'Neighborhood built environment and socioeconomic status in relation to physical activity, sedentary behavior, and weight status of adolescents', *Prev. Med.*, 110, pp. 47–54. doi: 10.1016/j.ypmed.2018.02.009.

Sallis, J., Floyd, M., Rodríguez, D. and Saelens, B. (2012) 'Role of Built Environments in Physical Activity, Obesity, and Cardiovascular Disease', *Circulation*, 125(5), pp. 729-737.

Sallis, J. F. and Glanz, K. (2006) 'The role of built environments in physical activity, eating, and obesity in childhood', *The future of children*, pp. 89-108.

Schicketanz, J., Grabenhenrich, L. and Lakes, T. (2018) 'An index for assessing activity friendliness for children in urban environments of Berlin', *DIE ERDE–Journal of the Geographical Society of Berlin*, 149(1), pp. 1-13.

Shankhwar, R., Datta, R., and Uniyal, N. (2021) 'An assessment of the Relationship between Vegetation (Forest Density Cover) Built-Up Area and City Land Surface Temperature, Generated by LANDSAT-8 OLI/ Thermalband - A Case study of Dehradun, India', *J. Mountain Res.*, 16(3), pp. 121-133.

Song, Q., Christiani, D. C., Wang, X. and Ren, J. (2014) 'The global contribution of outdoor air pollution to the incidence, prevalence, mortality and hospital admission for chronic obstructive pulmonary disease: A systematic review and meta-analysis', *Int. J. Environ. Res. Public Health*, 11(11), pp. 11822–11832. doi: 10.3390/ijerph11111822.

Summers, L. and Johnson, S. (2017) 'Does the Configuration of the Street Network Influence Where Outdoor Serious Violence Takes Place? Using Space Syntax to Test Crime Pattern Theory', *Journal of Quantitative Criminology*, 33(2), pp. 397-420.

Tappe, K., Glanz, K., Sallis, J., Zhou, C. and Saelens, B. (2013) 'Children's physical activity and parents' perception of the neighborhood environment: neighborhood impact on kids study', *International Journal of Behavioral Nutrition and Physical Activity*, 10(1), pp. 1-10.

Tesfazghi, E., Martinez, J. and Verplanke, J. (2010) 'Variability of Quality of Life at Small Scales: Addis Ababa, Kirkos Sub-City' *Social Indicators Research*, 98(1), pp. 73-88.

Tilt, J. H., Unfried, T. M., and Belen, R. (2007) 'Using objective and subjective measures of neighborhood greenness and accessible destinations for understanding walking trips and BMI in Seattle, Washington', *American Journal of Health Promotion*, 21(4), pp. 371-379.

Transportation Research Board (2005), 'Does the built environment influence physical activity? Examining the evidence', Washington, DC: TRB.

Turner, A. and Friedrich, E. (2010-2011) *Depthmap software, version 10.14.00b*. London: University College London.

Van Loon, J., Frank, L. D., Nettlefold, L. and Naylor, P. J. (2014) 'Youth physical activity and the neighbourhood environment: examining correlates and the role of neighbourhood definition', *Social Science & Medicine*, 104, pp. 107-115.

Wheeler, B., Cooper, A., Page, A. and Jago, R. (2010) 'Greenspace and children's physical activity: A GPS/GIS analysis of the PEACH project', *Preventive Medicine*, 51(2), pp. 148-152.

Wong, B.Y.M., Faulkner, G. and Buliung, R. (2011) 'GIS measured environmental correlates of active school transport: a systematic review of 14 studies', *International Journal of Behavioral Nutrition and Physical Activity*, 8(1), pp.1-22.

Zhang, Y., Mavoa, S., Zhao, J., Raphael, D. and Smith, M. (2020) 'The Association between Green Space and Adolescents' Mental Well-Being: A Systematic Review', *International Journal of Environmental Research and Public Health*, 17(18), p. 6640.

Zimmerman, M., Ramirez-Valles, J., Zapert, K. and Maton, K. (2000) 'A longitudinal study of stress-buffering effects for urban African-American male adolescent problem behaviors and mental health', *Journal of Community Psychology*, 28(1), pp. 17-33.