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The impact of street network connectivity on pedestrian volume

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Abstract

This paper investigates the impact of street network connectivity on pedestrian volume. Street network connectivity measured in most current studies captures only the metric characteristics of streets or physical connectivity. A whole different type of connectivity, visual connectivity, is largely ignored. Described in basic terms, higher physical connectivity means shorter travel time to reach the same number of destinations while higher visual connectivity means fewer turns to see the same number of destinations. Despite the correlation of these two connectivity constructs, studying both physical and visual connectivity is essential to better understand the role of street network on pedestrian activity. Using pedestrian counts of 302 street segments in Buffalo, New York, structural equation modelling highlights the multiple relationships between street network connectivity, built environment characteristics, and pedestrian volumes. Our findings suggest that both the conventional metric-based measure of physical connectivity and geometric-based measure of visual connectivity have significant positive impacts on pedestrian volumes, together with job density and land use mix. This outcome can encourage practitioners to pay attention to both the geometry of street network and its metric characteristics in order to create a pedestrian-friendly environment.

Keywords

physical connectivity, space syntax, visual connectivity, walkability

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Introduction

Building walkable environments has recently become a topic of interest among many urban planners and public health researchers (Cervero and Duncan, 2003; Ewing et al., 2003; Frank et al., 2004; Handy et al., 2002; Handy et al., 2005; Heath et al., 2006). The role of various built environment characteristics, such as population and job density,

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street connectivity, and land use mix, have been studied for their effects on pedestrian mode choice and walking frequency (Cervero and Kockelman, 1997; Clifton et al., 2007; Ewing and Cervero, 2001; Ewing and Handy, 2009; Ewing et al., 2006, 2013; Frank and Pivo, 1994; Frank et al., 2008; Lee et al., 2013; Moudon and Lee, 2003; Moudon et al., 2007; Pivo and Fisher, 2011). Literature suggests that street network connectivity is among the significant factors affecting pedestrian volume (Frank et al., 2005; Handy et al., 2003; Hillier, 2007; Maghelal and Capp, 2011; Moudon et al., 2007). Various measures of street connectivity have been used in the literature, including intersection density, average block length, block size, percentage of four way intersections, and link-node ratio (see these meta-analyses: Ewing and Cervero, 2010; Maghelal and Capp, 2011). Many studies found that smaller blocks and finer-grained urban street network may promote higher walking rates (Kerr et al., 2007) and increase the proportion and number of utilitarian and non-work walk trips (Lee and Moudon, 2006; Moudon et al., 2007).

We argue, however, that these conventional measures of street network connectivity capture only the metric characteristics of streets related to physical connectivity without considering the geometric characteristics related to visual connectivity. Our bodies interact with the built environment through a system of metric distances while our minds interact with the built environment through a system of visual distances (Hillier et al., 2010). Metric and visual distances can have different impacts on the decision making process for pedestrian behaviour, depending on the length and purpose of the trip (Hillier, 2009; Hillier et al., 2010). The difference between geometric and metric properties of street networks is illustrated in Figure 1. Grid 1 has a gridiron pattern with small blocks, grid 2 has irregular grid pattern with small blocks, and grid 3 has a gridiron pattern with large blocks. Grid 1 and grid 2 have relatively similar metric properties, with different geometric properties (i.e. a typical organic city in Europe vs. a typical planned city in the US). Meanwhile, grid 1 and grid 3 have similar geometric properties, with different metric properties (i.e. Portland with small block size vs. Salt Lake City with large block size).

Two neighbourhoods with similar intersection density and block length may have entirely different geometrical street patterns for visibility. Unlike physical connectivity where the actual physical distance matters, visual connectivity focuses more on the shape and geometry of the space, the way barriers are established, and how much they

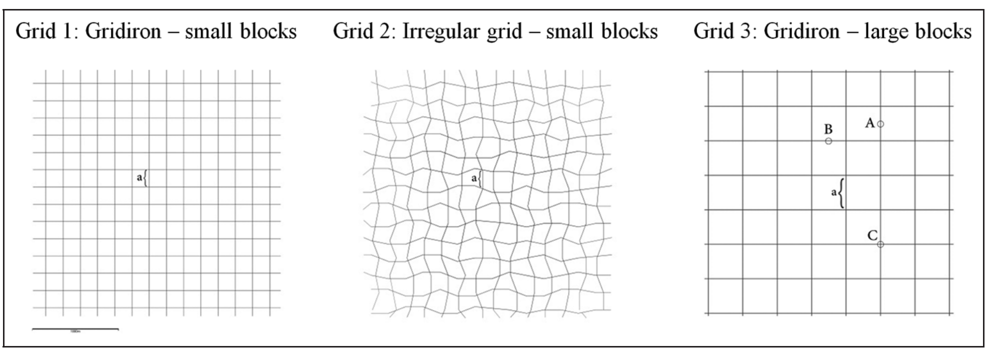

Figure 1. Three distinct street network patterns.

show or hide. A few studies have examined geometric characteristics and investigated the distinctions between gridiron versus curvilinear street patterns (Handy, 1992; Khattak and Rodriguez, 2005; Rajamani et al., 2003; Shriver, 1997). Curvilinear street patterns represent typical suburban patterns that often have curved alignments and usually branch out in hierarchical fashion, terminating in cul-de-sacs. Unlike curvilinear street networks, gridiron geometry allows long sight lines that can help pedestrians to better understand their surroundings and promotes better navigation through the street network.

The existing literature often ignores visual connectivity (see Carr et al., 2011; Frank et al., 2010; Handy et al., 2003), and no study has compared the impact of physical and visual connectivity on pedestrian volumes. We argue that both metric-based measures of physical connectivity and geometric-based measures of visual connectivity are important to better understand the role of street network on pedestrian volumes. In this paper, street network visual connectivity will be measured using space syntax methodology, which has not been used much in the United States (Raford, 2010).

This research fills a gap in the literature by providing an improved and nuanced understanding of the conceptual differences between physical and visual connectivity. This comprehensive examination of connectivity measures may be useful to multidisciplinary researchers and practitioners, who are interested in ways to improve physical activity outcomes. In addition, this research may help resolve claims that street connectivity has an indirect effect on pedestrian volumes through their effects on land use patterns, particularly on density and land use mix (Hillier, 1996, 2009). Structural equation modelling will be used to help understand the complex interrelationships between street network connectivity, density, land use mix, and pedestrian volumes.

Street connectivity and pedestrian volume

Space syntax

Space syntax is a set of theories and techniques for measuring the spatial configuration of street networks. By focusing on street networks rather than buildings or parcels to describe the built environment, space syntax analysis considers spatial properties of physical space (Hillier, 2007). The basic element in space syntax is the street *segment* between intersections, which can be derived from road centre line data with the help of Depthmap software, developed by Space Syntax Limited (Turner, 2007). The street segments can be translated into a graph, in which segments and their connections turn into nodes and links. Based on this topological representation, space syntax uses two different definitions of the distance between each segment and its neighbours, and calculates two measures. Two distance definitions are: (1) *metric-based*: 'the distance in metres between the centre of a segment and the centre of a neighbouring segment'; and (2) *geometric-based*: 'the degree of the angular change of direction between a segment and a neighbour' (e.g. right angle turn is counted as 1 turn; 45 degree angle is counted as 0.5 turn, and so on.) (Hillier, 2009: 3).

Shortest path maps can be generated using the metric definition of distance, and least angle change maps can be generated using the geometrical definition. Two space syntax measures are: (1) *integration*, which measures how close each segment is to all others under each definition of distance; and (2) *choice*, which is used to calculate 'how many distance-minimizing paths between every pair of segments lie on each segment under different definitions of distance'

(Hillier, 2009: 3). Both measures can be analysed at a local scale or global scale. The radius of locality, which is the number of turns departing from each segment, can also be computed in either geometric or metric distance. In case of a geometric radius of 3, for instance, only 3 *complete turns* are counted departing from each street segment.

Metric versus geometric based measures of street network connectivity

Revisiting Figure 1, for a given segment '*a*' in each grid, four connectivity measures can be compared, including two space syntax measures (geometric integration R-3,[1] metric integration R-800m[2]), and two conventional measures (intersection density within a 400 metre buffer, and average block length within a 400 metre buffer). Figure 1 shows that segment '*a*' in grids 1 and 2 have a relatively similar metric integration, intersection density and block length, despite having different geometric integration. Conversely, segment '*a*' in grids 1 and 3 have similar geometric integration, but different metric integration, intersection density, and block length.[3] This example illustrates that conventional measures are not sufficient to capture the geometrical differences between street network patterns.

Space syntax can be used to capture geometric aspects of street patterns by defining distance beyond metric distance as the least angular change distance. For example, in metric space, point *B* compared to point *C* is closer to point *A*. Put differently, considering point *A* as the origin, point *B* is more accessible than point *C* in *metric distance*. In geometric space, point *C* compared to point *B* is closer to point *A*, because, visually, *A* and *C* are better connected to each other than *A* and *B*. In other words, it takes *fewer turns* to go from point *A* to *C*. In general, point *C* is more *visually connected* than point *B*, because more locations can directly connect to point *C* than point *B*. This example shows that measuring visual connectivity is possible by studying and measuring the geometric aspect of street patterns. The space syntax technique can help to measure geometric properties as well as metric properties of street networks.

Direct impact of street connectivity on pedestrian volume

We hypothesise that both metric characteristics of the urban grid related to physical connectivity and geometric characteristics related to visual connectivity can explain natural movement. Natural movement is the proportion of movement on each street segment that is determined by the structure of the urban grid itself rather than by the presence of specific attractors or destinations (Hillier, 2007). To be physically connected, a space has to be well-connected in terms of paths and circulation and free from physical barriers, such as fences or walls. To be visually connected, a location needs to be seen from certain points. Visibility is important to make people feel free or invited to enter a space and feel welcome in it.

In four neighbourhoods of London, Hillier and Iida (2005) found much lower correlation between pedestrian counts and physical connectivity (metric integration value) than between visual connectivity (geometric integration value) and pedestrian counts. Hillier (2007) argued that pedestrian movement can usually be best predicted by calculating visual connectivity using a geometric integration value in radius 3, while predicting the movement of a car would use a higher radius for integration. This is because car journeys are generally longer and therefore drivers read the matrix of possible routes according to larger-scale logic than pedestrians.

Indirect impact of street connectivity on pedestrian volume

High levels of street connectivity can attract retailers, commercial uses, and high density in general (Ewing, 2000; Hillier, 2009; Hillier and Vaughan, 2007), which are considered as pedestrian attractors and generators (Frank and Pivo, 1994; Handy et al., 2005; Maghelal and Capp, 2011). Street connectivity, therefore, may have an indirect impact on pedestrian volumes by influencing other built environment characteristics such as density and land use mix. For instance, more retailers and commercial uses appear in the more integrated parts of the city (Hillier, 1996, 2007). Therefore, attractors may reinforce natural movement, acting as multipliers.

Patterns of streets have often developed over decades and centuries. Many streets survive largely unchanged. Therefore, they are the most resilient morphological element compared with land use, building structures, or even plot patterns (Conzen, 1960). On the other hand, land uses are relatively temporary compared with buildings, lots and streets. Changes to land uses often happen either by adopting and converting a building, or by constructing a new building. In both cases it is much easier than changing or expanding street networks. Therefore, streets can exert a powerful long-term influence on urban form. Many urban designers refer to street network as an 'armature', meaning a generator of urban form (Carmona et al., 2010).

Critics like Ratti (2004a, 2004b) argue that the impact of street network on attractors can only be true in an organic city, but not applicable in a planned city. For example, suburban malls and office buildings are not necessarily located in the most integrated street segments. Hillier and Penn (2004), however, counter that the emergence of suburban malls and offices are partially due to the expansion of street networks at the metropolitan level. In order to test the indirect impact of street network on pedestrian volume in the context of an American city, we treat the street network as exogenous and land uses as endogenous in a structural equation model.

Research method

This research was conducted in two phases. The first phase included data collection and processing. The second phase included a structural equation model to show the effect of two street network connectivity measures (intersection density as physical connectivity and Integration R3 as visual connectivity) on pedestrian volumes, through the mediating influences of job density, population density, and land use mix.

Study area: City of Buffalo, New York

Our case study city, Buffalo, is located in Western New York on the eastern shores of Lake Erie and has a population of 261,310 (US Census Bureau, 2010). The evolution of urban form in Buffalo is due to its past boom and decline. Buffalo was a small trading community from 1789 to 1804, when surveyor Joseph Ellicott designed a plan using a regular grid that is interrupted by diagonal avenues. As the city began to grow in size, the core of the city was kept intact and the extension of diagonal avenues gave a star-shape to its street network. A regular grid of downtown, wide railroads in the southeast, and the industrial riverfront in the southwest were the main physical structures of the city. By 1900, Buffalo was a boomtown with a major railroad and active port at the western end of the Erie Canal. Urban growth has almost stopped and its spatial structure has been virtually untouched since the mid twentieth century (Figure 2).

Buffalo has a semi-regular grid similar to Savannah, Philadelphia, and Washington that represents a more complex street network pattern than later American cities. The

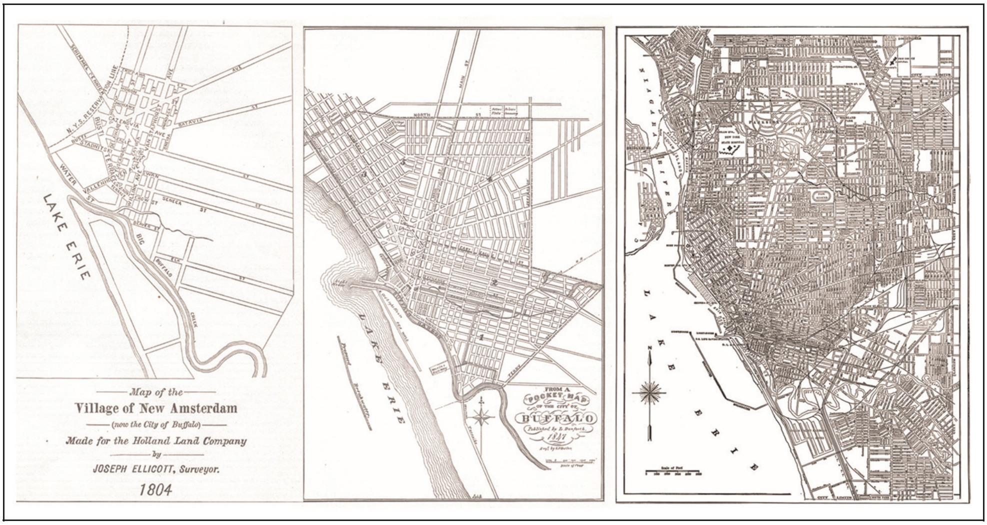

Figure 2. Evolution of street network in Buffalo City, NY, from left to right: (1) Village of New Amsterdam, made for Holland Land Company by Joseph Ellicott, 1804; (2) From Smith's *History of the City of Buffalo and Erie County*, published by L Danforth, 1847; (3) From PF Collier and Son's *The New Encyclopaedic Atlas and Gazetteer of the World*, 1909. *Source:* buffaloresearch.com (2014).

variety in the proportion and size of blocks differentiates Buffalo from the typical homogenous street pattern of other American cities. Morphologically, Buffalo is an interesting city with locally regular grids, and a deformed grid at the larger scale. The hierarchy of streets and the nucleus centre can be traced easily by looking at the street network. Based on these characteristics, Buffalo's street segments are morphologically heterogeneous, and thus an interesting case to study the effect of both geometric and metric measurements of street network connectivity on pedestrian volume.

Data collection and processing

In this study, graduate urban planning students of the University at Buffalo, The State University of New York counted the number of pedestrians on 302 sampled street segments from 2007 to 2010 on a weekday. Data were collected for multiple years at the same location to capture consistent patterns of pedestrian volume over the years. To get a citywide sample of pedestrian volumes, the City of Buffalo was partitioned into 22 equally sized rectangular zones, and street segments were selected randomly from each. In addition, students asked Buffalo residents to mark the streets that they thought are most walkable and least walkable on a map. These marked street segments were added to the sample of randomly selected streets. Pedestrian counts were only conducted on the side of the road where students were standing. Pedestrian flow on each segment was observed twice, once during peak hours and the other during off-peak hours. Photos taken at the time of pedestrian counts were used to verify the data collected. Our dependent variable is the peak hour observed pedestrian count on each street segment.

To generate visual connectivity measure, street centre line data for 2010 were downloaded from the New York State GIS ClearingHouse, and were analysed with least angle space syntax technique (geometric analysis) using Depthmap 10. The processed

Figure 3. Visual connectivity: Integration R3: street network of Buffalo City, NY.

data were then exported to ArcGIS to be complied with other data for subsequent analysis. Figure 3, a map of *integration-R3* values of the street network in Buffalo, shows that the downtown area and the main diagonal connector roads are highly visually connected to their surrounding neighbourhoods.

Other data were collected from the City of Buffalo, New York State GIS Clearinghouse and the US Census Bureau. Table 1 defines the variables used in the structural equation model, along with data sources, the geographical scale of measurement, and a brief computation process.

Modelling process

Structural equation modelling

We developed a structural equation model (Byrne, 2010; Hoyle, 2012; Ullman and Bentler, 2001) to show the effect of two street network connectivity measures (intersection density as physical connectivity and Integration R3 as visual connectivity) on pedestrian volumes, through the mediating influences of job density, population density, and land use mix. Based on the theory of natural movement, street connectivity can have both direct and indirect impacts on pedestrian volumes. Given the hypothesised interrelationships between the built environment variables and pedestrian volumes, we decided to use structural equation modelling (SEM) to estimate our model.

This technique has been used to study the relationship between the built environment and travel behaviour (Cao et al., 2007; Cervero and Murakami, 2010; Rutt and Coleman, 2005) because it can account for confounding, mediating, and moderating

Table 1. Variables, their sources and computation process.

Variable name	Variable description	Data source and computation	Descriptive statistics	
			Mean	Standard deviation
Pedestrian_Counts	The number of pedestrians observed at given street segment during peak hours.	Pedestrians counted by the graduate urban planning students of the State University of New York at Buffalo in 2007–2010 that include 302 street segments.	10.96	11.35
Integration_R3	Space syntax geometric measure (least angle technique) with the radius of 3 shows how close each segment is to all other segments in 3 complete turns.	Using US Census TIGER/line for street centre lines and editing it according to pedestrian accessibility, the computation was done in Depthmap 10. (Segment analysis: least angle change.)	3161.83	2297.50
Intersection density	The number of intersections within 400 metre buffer divided by the gross area of the buffer.	Intersections were computed in ArcGIS based on street centreline file from the University at Buffalo, The State University of New York State GIS Clearinghouse.	159.5	71.6
Population density	The population density measured in 1000 residents per square mile within the adjacent blocks of any given street segment.	2010 census blocks were used for calculation of population density.	1.61	0.74
Employment density	The employment density measured in 1000 job per square mile within the adjacent blocks of any given street segment.	2010 LED data at block level were used for calculation of employment density.	15.21	21.66
Land use mix (entropy)	Entropy is related to the number of different commercial land uses in a given area and the degree to which they are balanced in employment. Retail, entertainment, health, education, and personal services are the five categories that were used to calculate entropy.	The shares were computed based on employment of five types of services within adjacent blocks of any given street segment. Employment data were collected from LED, Census Bureau.	0.51	0.21

variables all at once. Byrne (2010: 3) explained the term *structural equation modelling* based on two important aspects of the procedure:

> (a) that the causal processes under study are represented by a series of structural (i.e. regression) equations, and (b) that these structural relations can be modelled pictorially to enable a clearer conceptualisation of the theory under study. The hypothesised model can then be tested statically in a simultaneous analysis of the entire system of variables to determine the extent to which it is consistent with the data. If goodness-of-fit is adequate, the model argues for the plausibility of postulated relations among variables; if it is inadequate, the tenability of such relations is rejected.

We faced two options for constructing the SEM model: (1) include all built environment and demographic variables (such as crime, distance to transit, income, etc.) that are found to be related to pedestrian activity; or (2) use the main built environment predictors, suggested by literature. It was a trade-off between developing a complete model, which captures every possible relationship but is, as a result, potentially complex and difficult to interpret, or developing a simple structure which is more interpretable and captures the essence of relationships. We chose the second, focusing only on the main predictors in a simple model. *Integration-R3* was used to represent visual connectivity. *Integration* is the first original space syntax measure proposed by Hillier and Hanson (1984) and the most commonly used measure in the space syntax literature (Hillier et al., 2010; Yin, 2013). Among metric measures, *intersection density* was chosen to represent the construct. It is the most widely used connectivity measure in the existing literature (Ewing and Cervero, 2010; Maghelal and Capp, 2011). Job density, population density, and land use mix were used to represent land use mediators along the causal pathways between street network design and pedestrian volumes (Ewing and Cervero, 2010; Frank and Pivo, 1994; Handy et al., 2005).

Figure 4 shows the path diagram for the SEM model estimated in this paper. The outcome variable of pedestrian volume is in the white box, with predictor variables directly feeding into it via path arrows, or indirectly through other predictors. The key predictor variables are the connectivity variables shown in black boxes. Paths are represented by straight lines with an arrowhead pointing from the cause toward the effect. Curved lines with arrowheads at both ends represent correlations. *Integration_R3* and *intersection density* are correlated, of course, but are treated as exogenous. AMOS 7.0

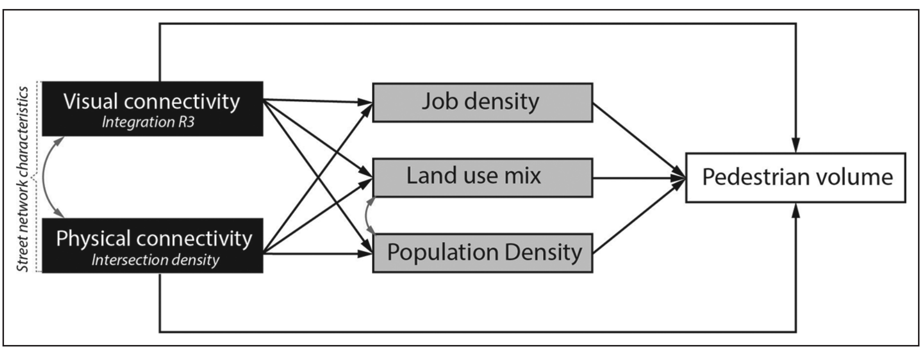

Figure 4. Path diagram of factors influencing pedestrian volume.

Table 2. Maximum likelihood estimates: Standardised regression weights (group number 1: Default model).

			Standard estimate	P
Job density	←	Integration R3	0.131	0.017
Job density	←	Intersection density	0.395	< 0.001
Pop density	←	Integration R3	–0.130	0.025
Pop density	←	Intersection density	–0.250	< 0.001
Land use mix	←	Intersection density	–0.107	0.071
Land use mix	←	Integration R3	0.209	< 0.001
Pedestrian counts	←	Pop density	0.072	0.184
Pedestrian counts	←	Job density	0.383	< 0.001
Pedestrian counts	←	Land use mix	0.100	0.059
Pedestrian counts	←	Intersection density	0.142	0.016
Pedestrian counts	←	Integration R3	0.116	0.034

Summary statistics: N = 302; chi-square = 1.336; probability level (>0.05) = 0.513; CFI (>0.90) = 1.000; NFI (>0.90) = 0.993; TLI (>0.90) = 1.026; RMSEA (<0.6) = 0.000.
CFI = comparative fit index; NFI = normed fit index; TLI = Tucker Lewis index or non-normed fit index; RMSEA = root mean square error of approximation.

Table 3. Structural equation model, linear estimate (model summary dependent variable = pedestrian count).

Independent variables	Standardised direct effects	Standardised indirect effects	Standardised total effects
Intersection density	0.142	0.122	0.264
Integration R3	0.116	0.062	0.178
Job density	0.383	0.000	0.383
Land-use mix	0.100	0.000	0.100
Population density	0.072	0.000	0.072

software package (SPSS Inc.) was used to estimate the path model shown in Figure 4.

Results and interpretations

Tables 2 and 3 present the results of structural equation modelling. It is generally recommended that multiple indices be considered simultaneously when overall model fit is assessed. Table 2 reports different model fit indices. The result shows that our model fits the data well.

Table 2 presents the standardised coefficients and the p values, and Figure 5 presents the path diagram of SEM with standardised coefficients. Table 3 shows direct, indirect, and total standardised coefficients, which are the sum of direct and indirect coefficients. Job density has the highest total coefficient (0.383) among all built environment variables. This finding indicates that the more jobs adjacent to a given street segment, the more pedestrian activity at that street segment. Both types of connectivity measures have a significant positive impact on job density. (Integration R3: Estimate = 0.131; P value = 0.017- Intersection density: Estimate = 0.395; P value < 0.001). On the

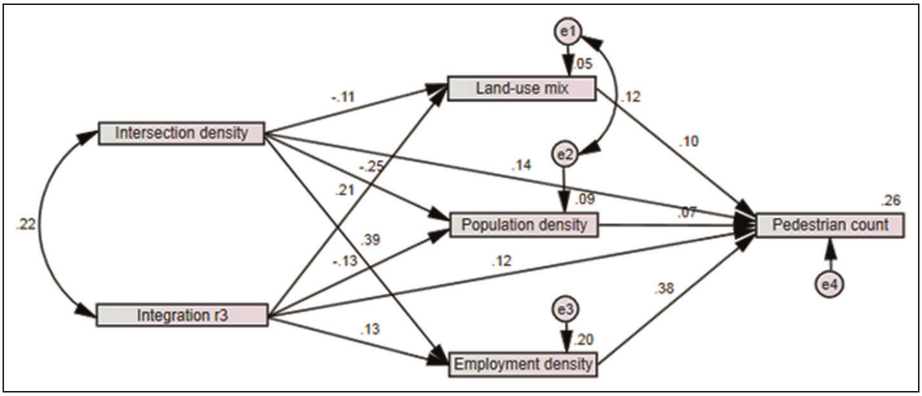

Figure 5. Path diagram of SEM with standardised estimates.

other hand, both types of connectivity measures have significant negative impact on *residential density* (Integration R3: Estimate = –0.130; P value = 0.025- Intersection density: Estimate = –0.250; P value < 0.001). The impact of *intersection density* on *land use mix* is not significant, but *Integration_R3* shows a significant positive impact on *land-use mix* (Estimate = 0.209; P value = 0.025). In addition, *Land-use mix* shows a positive impact on pedestrian count at the significance level of 0.1 (Estimate = 0.100; P value = 0.059). However, the impact of *population density* on pedestrian movement is not significant in our model.

Both visual and physical connectivity measures have significant positive direct effects on pedestrian counts (Integration R3: Estimate = 0.116; P value = 0.034- Intersection density: Estimate = 0.142; P value < 0.001). The total effect of *intersection density* (0.261) is relatively higher than *Integration-R3* (0.178). That is due to the high impact of intersection density on job density. Therefore, physical connectivity, compared with visual connectivity, might be a stronger factor for the emergence of office and commercial uses. *Intersection density* and *Integration-R3* have direct effects on pedestrian volume, and indirect effects through *population and employment density* and *land use mix*. Our model results confirm that the conventional measure of physical connectivity in urban planning literature has a significant impact on pedestrian movement, as suggested by the literature. In addition, the visual connectivity (Integration_R3) also has a significant direct effect independent of physical connectivity.

Discussion and limitations

While the effect of visual connectivity has been neglected in most studies of the influence of built environment on travel behaviour in the United States, this study shows the significance of including this street connectivity measure as an exogenous influence on pedestrian volumes. Our finding is consistent with Hillier (1996, 2007) that commercial uses prefer locations with high connectivity, while residential uses often prefer segregation and privacy. The positive impact of *land-use mix* on pedestrian count is also congruent with the literature (Frank and Pivo, 1994; Handy et al., 2005; Maghelal and Capp, 2011). Finally, the direct effect of both measures of connectivity on pedestrian volumes is consistent with the literature (Handy et al., 2003; Hillier, 2007;

Maghelal and Capp, 2011; Moudon et al., 2007).

We acknowledge the limitations of this study both in validity and reliability. Focusing on one city limits the external validity of our findings. We recommend replicating this study in more typical American cities with simple gridiron layout. Comparing the walkability of cities with diverse street network geometry, such as Boston, Washington, DC, and Detroit, or comparing cities with the same geometrical properties but different metric properties, such as Salt Lake City, Atlanta, and Portland, can add to the external validity of our findings. Our second research recommendation is to conduct longer standardised counts on each street segment in any future study for more reliable results.

Conclusion

This study makes three important contributions to the field. First, our results support findings from current studies that certain built environment properties, such as density and land use diversity, have an impact on pedestrian volume. Drawn from the pedestrian counts of 302 street segments of Buffalo, our findings revealed that higher street network connectivity, population density, job density and land use diversity are associated with increased pedestrian volume.

Second, this paper provides guidance on how to systematically describe different dimensions of the connectivity construct. Many different terms and measurements are currently used to represent connectivity in the literature; however, there is no evidence of standardisation or classification to ensure that future urban design studies rest on a shared language. Previous studies have proven that high connectivity decreases travel distances for pedestrians – the physical dimension – and provides more direct travel between destinations – the visual dimension. This study links the nature of each dimension to the metric and geometric properties of street networks and demonstrates that, despite their covariance, visual and physical connectivity are independent dimensions of the connectivity construct.

Third, our findings offer further confirmation of the accumulating body of evidence that street network connectivity is not only among the factors that have the highest and the most resilient impact on walkability, but it also has a strong impact on other built environment characteristics, such as density and diversity. This suggests that the generating process of urban form is highly dependent upon the street network pattern as suggested by Hillier in his *theory of natural movement*. In addition, connectivity is dependent on the street network, which is much more resilient to change compared to building structures, while other aspects of urban form, such as density or land use mix, are dependent on building structures. This may illuminate why in some cities with a certain street network pattern, it is difficult to promote higher density and diversity, and consequently, walkability.

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Notes

1. Defined distance: geometric (least angular change); local radius: 3 turns.
2. Defined distance: metric; local radius: 800 metres.
3. Segment *a* in grid 1: Integration R-3 = 294, Integration R-800 = 62, intersection density = 30, average block length = 61. Segment *a*

in grid 2: Integration R-3 = 182, Integration R-800 = 69, intersection density = 29, average block length = 64. Segment *a* in grid 3: Integration R-3 = 294, integration R-800 = 22, Intersection density = 120, average block length = 122.

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