An Exploratory Step to Evaluate the Pedestrian Flow in Urban Environment

Mauro D'Apuzzo[1], Daniela Santilli[1(✉)], Azzurra Evangelisti[1], Vincenzo Pelagalli[1], Orlando Montanaro[1], and Vittorio Nicolosi[2]

[1] Department of Civil and Mechanical Engineering DICEM, University of Cassino and Southern Lazio, Cassino, Italy
{dapuzzo, daniela.santilli}@unicas.it, aevangelisti.ing@gmail.com
[2] Department of Enterprise Engineering "Mario Lucertini", University of Rome "Tor Vergata", Rome, Italy
nicolosi@uniroma2.it

Abstract. The pedestrian accounts for part of the road safety problem in most developed countries. Pedestrian accidents are thus an urgent issue for safety improvement, particularly in urban area. Furthermore, recent sustainable mobility oriented policies are boosting walking in urban areas. In order to cope with this increase in pedestrian flows, European municipal authorities, responsible for road safety, traffic management and mobility, need reliable engineering methods to plan urban road safety and protect vulnerable users.

Road safety management systems are usually developed to identify hazardous sites and to find suitable countermeasures. Risk exposure assessment is required to identify sites with high accident potential. This assessment requires the knowledge, on one side, of the known vehicular flows and, on the other, of the pedestrian flows, which are not normally known to road operators.

In this paper a methodology to develop and calibrate forecasting model aimed at evaluating pedestrian exposure is presented. The model is based on original approach that integrates the Space Syntax modelling framework with pedestrian mobility aspects and a calibration procedure was proposed that use counts on a limited number of roads. Preliminary results derived from a case study in an urban environment seem promising and confirm the model's good ability to predict pedestrian flows.

Keywords: Urban pedestrian exposure · Space syntax · Hybrid approach

1 Introduction

In recent years, several countries have been looking for solutions to reduce environmental pollution (noise and air) in urban environment; sustainable mobility has therefore become an effective measure to reduce traffic pollution. Within this framework, multimodal transport alternatives that are more environmental-friendly such as public transports services, electric vehicles, cycling and walking are constantly promoted to replace the use of the private internal combustion vehicles.

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However, it has to be acknowledged that pedestrians in cities often conflict with other traffic components because the infrastructure is often not properly designed.

In this connection, in Italy, as well in other countries, vehicle-pedestrian collision data are routinely collected through law enforcement reports. These reports are often of limited value because of poor information on collisions with minor damage, on accident location, and, above all, on pedestrian exposure. Furthermore, the evaluation of pedestrian exposure is not a simple task since several studies have shown that pedestrian activity is affected by the network connectivity and other variables such as population, land use, purpose of travel, travel mode, etc. [3, 14, 16].

To correctly design the road infrastructure, it is necessary to evaluate the risk that, in road traffic, is a function of three factors: the first is the exposure (the amount of movement or travel within the system by different users or a given population density), the second is the underlying probability of a crash, given a particular exposure and the third is the probability of injury, given a crash. Exposure is defined as the percentage of pedestrians in contact with potentially harmful vehicular traffic [20]. Under simplified assumptions, at intersection level, risk can be evaluated as the annual number of vehicle-pedestrian collisions divided by the product of annual pedestrian and vehicle volumes estimated at a given intersection [13, 17].

In order to assess this risk, it is necessary to describe pedestrian mobility and therefore to know the extent of the flows and to model their distribution on the road network.

Pedestrian mobility can be reconstructed by estimating the number of people who, based on their choices, move over a period of time mainly for work, study, shopping or other purpose according to the distribution of pedestrian trip "attractors" located within a proximity area. Numerous theories have been proposed to analyze pedestrian mobility such as: stochastic model [2], transition matrix model [6, 15], queuing models [10, 19], route choice model [10] and others. Most of these models are used to describe critical situations (emergency exits, emergency evacuations, etc.), but due to the complex formulations they are difficult to be applied in real contexts. Path selection models such those used within the Space Syntax framework using a graphical "proximity" algorithm seem to offer an effective trade-off between complexity and easiness to implement, in order to estimate pedestrian movement potentials.

In this work a new methodology based on Space Syntax framework was used to estimate pedestrian exposure. The methodology has been calibrated by means of pedestrian counts on a limited number of urban roads within a case study.

2 Space Syntax

Space Syntax is based on a series of theories and techniques for the analysis of the spatial configuration of road networks and buildings, and of the interactions that coexist with each other. It was conceived by Bill Hillier, Professor of the Bartlett School of Architecture, University College London (UCL), in the late 1970s. Space Syntax was created to help urban planners to simulate the likely social effects (intended as human behavior and business development) generated by their projects; in fact he defines it as: "*Space syntax ... is a set of techniques for the representation, quantification, and interpretation of spatial configuration in buildings and settlements*." [8].

According to this approach, the pedestrian movements are influenced by the configuration of the network. The configurational approach assumes that the urban space, as it is structured, influences both the settlement processes and the movement on roads and spaces [9].

Space Syntax is able to perform analysis considering both an arbitrary closed space or one-dimensional structures. For the estimation of pedestrian flows, the axial analysis technique is usually preferred where the two-dimensional urban space is reduced in a one-dimensional system. In fact, the road network is schematized with a network made up of linear segments. Once a line (road) has been selected, as starting point, this line will intersect other n lines, which are numbered according to how many changes of direction separate it from the starting line. The hypothesis is that the observer moves according to visual perception, preferring linear paths not related to visual variations because travel seems shorter [21].

All movements estimated by Space Syntax are defined by Hiller as natural movements [8]. The latter are the relationship between the configuration of the network and each other element of the road system. In many cases the displacements are not only generated by the network configuration but can also be influenced by other attractors.

The main morphological parameters of Space Syntax are: connectivity, depth and integration. Connectivity represents the number of lines that directly intersect a particular axial line. Depth is defined as the minimum number of changes of direction to reach any other segment of the network from the origin [1]. This parameter cannot be used to compare the layout of the roads in different cities, as it is influenced by the total number of nodes in the system. Different road layouts can be evaluated by means of the integration parameter representing how well the initial segment is integrated into the global system, where higher integration means greater connection to the network.

The type of analysis that takes into account the geometric, topological and angular characteristics of the network, producing the best results in terms of traffic flow forecasting is the *Angular Segment Analysis with Metric Radius, (ASAMR)*. This analysis is based on the calculation of the angular depth of each section in relation to the other sections of the network, setting a buffer with finite metric radius within which the connections between the sections are evaluated [1]. The angular variation represents the "cost" of the move. According to Hillier [9], in fact, the ability of the road user to plan the most convenient route from point A to point B is linked to his perception of the distance to travel. This distance is unconsciously evaluated on the basis of tortuosity (expressed as angular variation). The user is willing to travel more road, "spending less" in terms of tortuosity (Fig. 1).

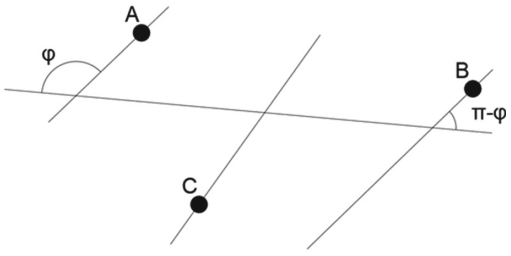


Fig. 1. Angular variation between the sections of the network

All this is evaluated within a buffer with a variable metric radius depending on the purpose of the analysis. For the evaluation of pedestrian flows in an urban center, a radius of 400 m is usually assumed (according to the impedance functions [12]), corresponding to a typical 5 min trip on foot. With this restriction, the system will calculate the angular turns of all sections within 400 m of the current section; path deviations beyond this radius will not be calculated. Therefore the system will identify only local relationships between elements within 400 m from each of the segments. The analysis returns among the many configurational parameters of the network, Integration (INT) and Choice (CH), which contain an intrinsic meaning relating to the probability of each road segment of being chosen or not in the different possible paths from an Origin to a Destination. Integration represents a good indicator of how each of the segments can be a highly desired destination by users; while Choice indicates the probability that each segment can be chosen by pedestrians as the shortest route.

Integration has been correlated with pedestrian flows, in different contexts [5, 7, 18]. However till now, poor correlation coefficients ranging between 0.2 and 0.4 have been obtained. Since the pure configurational approach does not seems to entirely capture the nature of urban pedestrian activities, it was proposed to use an "hybrid" approach that integrates the configurational analysis performed within the Space Syntax approach with the land use and pedestrian trip behavior in order to obtain better forecasts.

3 Description of Procedure

The analysis conducted in this study can be divided into two phases.

In the first, the road and pedestrian network was derived, creating the spatial relationship of contiguity between the census sections and the sections of the road system. The values of the population (obtained from Italian National Institute of Statistics, ISTAT, Databases) in the census sections were attributed as an average to the sections of the network through the proximity approach. This approach correlates the characteristics of each of the network centroids (i.e. the central point of each road segments) with the surrounding ones, according to a sequence of buffers with increasing radius. The radii of the buffers range from 100 to 1600 m and are chosen on the basis of an impedance function [12] that describes the propensity/probability to travel (expressed in term of a dimensionless parameter, k) of pedestrians as the distance to travel varies.

A typical impedance function is shown below, with a table reporting the k values as a function of the pedestrian travel distance assumed by the buffers (Fig. 2 and Table 1).

For each network centroid, a weight *Pprox* is obtained; this is assessed at an increasing distance from the single centroid, taking into account the actual propensity of users to move as their distance from it increases. The aim is to define a *weight factor*, expressed in term of attractiveness of pedestrian flows as a function of the average of the population living in the specific circular crown area for each road segments.

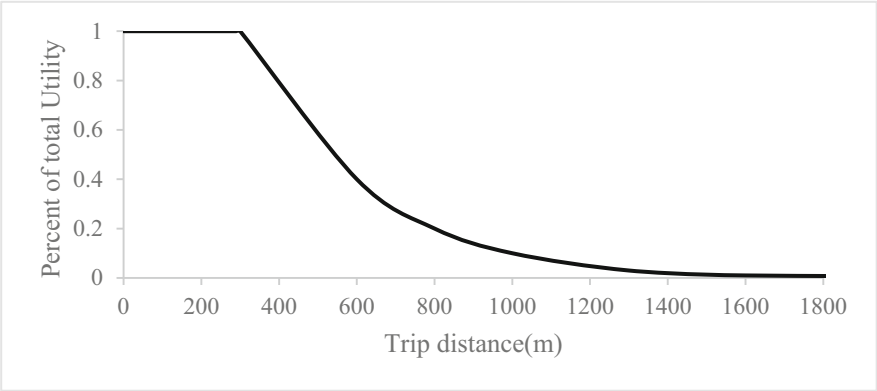


Fig. 2. Impedance function for pedestrian movement

Table 1. Table of mean k values for each circular crown

Distance (m)	k
0	1.00
100	1.00
300	1.00
600	0.40
800	0.20
1000	0.10
1300	0.03
1600	0.01

In the second phase, configurational analysis within the Space Syntax framework is carried out and a comparison is performed with corresponding pedestrian counts for each road segment. In detail, "weighted" and "unweighted" analysis are carried out to evaluate the effectiveness of the new "hybrid" approach with that provided by a conventional configurational analysis in predicting the pedestrian flows in a real urban context.

4 The Simulations and the Case Study

In order to calibrate and validate the model, the city of Cassino (FR) was analyzed. This municipality of Lazio region has about 36000 inhabitants (Figs. 3 and 4).

The study area examines only the city center. The socio-demographic data necessary for the analysis can be obtained from the ISTAT website on the census sections (about 60) of the analysis area. The idea behind this study was to use the population that insists on each road segment as weights. This stems from the consideration that although an area of the road network can be geometrically and topologically "attractive", well connected and integrated, it will be affected by quantitatively different pedestrian flows depending on the resident population.

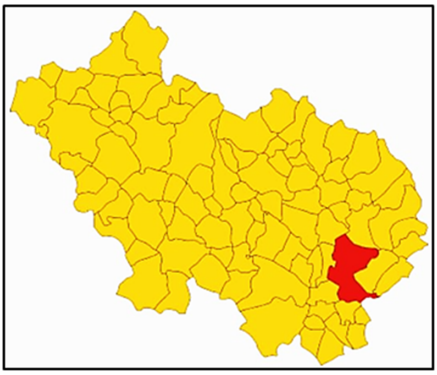


Fig. 3. The position of the municipality of Cassino in the province of Frosinone is shown in red (Color figure online)



Fig. 4. Aerophotogrammetry of Cassino center, with the study area highlighted in red (Color figure online)

Once the network was defined, the Space Syntax model was calibrated, attributing, to each road section, a weight connected to the population residing in the various census sections whose population was assumed, under conventional simplifying assumptions, concentrated in their center of gravity or "census section centroid".

4.1 Collection of Pedestrian Exposure Data

Before proceeding with the simulations, some counts were made on some of the main road sections or those characterized by the presence of attractors. For the identification of pedestrian flows, it was decided to proceed with a visual survey conducted by one or more operators by means of video. A moving observer approach for pedestrian count was adopted as investigation technique. According to this approach, videos were made, by different software, from inside a vehicle moving on the route to be examined (Fig. 5).



Fig. 5. Layout example of video cameras positioning in the moving observer survey

The advantage was that the human operator has the able to discriminate between different pedestrian activities (standing, moving or crossing) according to different directions, although longer times to process the data can be expected.

To determine the route, the areas of major pedestrian attraction were taken into account. Two itineraries have been created (one for the weekday and one for a pre-holiday day), both with the same starting and ending points (Figs. 6 and 7).



Fig. 6. Pre-holiday route



Fig. 7. Weekday route

Experimental campaign was carried out in the peak-hour period within the day: on weekdays the following three observation periods have been considered: from 8.00 to 9.00, from 12.00 to 14.00 and in the evening from 18.00 to 19.00.

As for the pre-holiday day, three observation periods were investigated in the morning (8.00–9.00, 9.00–10.00, 10.00–11.00) to highlight pedestrian activity near the market areas and one in the evening (20.00–21.00) in areas close to temporary pedestrian zones.

Following the video processing, the number and position of pedestrians was obtained in the different investigation periods (Fig. 8).

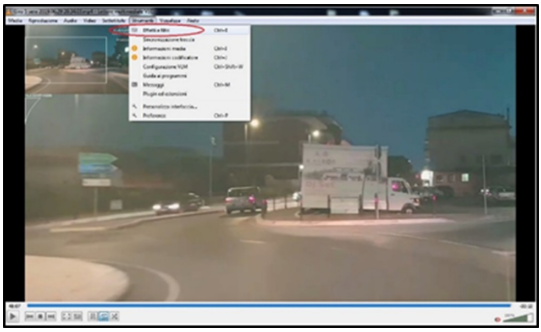


Fig. 8. Example video processing

4.2 Results from Configurational Analysis

Following the analyzes carried out by means of Space Syntax, different results were obtained if weight was used or not. In Fig. 9 a contour map of the road network showing the Integration parameter level provided by the simple configurational analysis via the ASAMR approach was conveniently depicted. This parameter was chosen because according to most of scientific literature, it seems to be the one exhibiting the highest correlation with pedestrian movements actually observed on the network [4, 9].

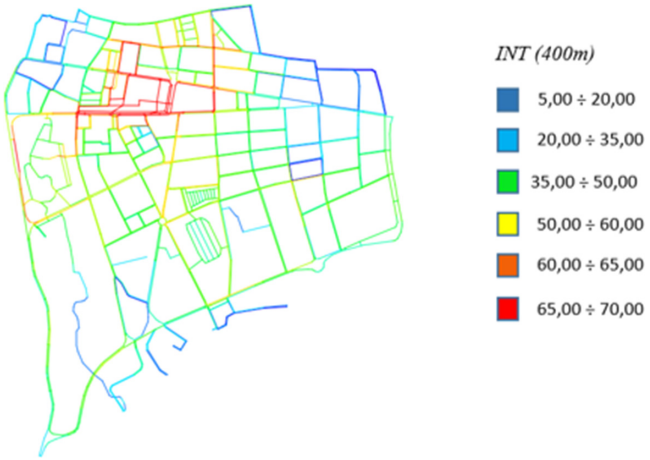


Fig. 9. Result of the configurational analysis (not weighed) on the Cassino network

Segment Analysis – Unweighted

It has to be highlighted that the simple configurational analysis (unweighted) depicted in the Fig. 9 refers only to the geometric and topological characteristics of the network.

The area of the center, with sections more interconnected to each other, was the one in which highest values of Integration were reached. As it can be observed, Integration values decrease moving away from Central Business Distric (CBD) to peripheral areas with less connectivity.

Segment Analysis – Prox Weight

Unlike the previous analysis, the combined effect determined by the population geographical distribution and by the pedestrian willingness to move has been taken into account by the hybrid approach employing the Prox-weighted analysis (Fig. 10). The central area continues to have high Integration values (10,000–12,000), due to the connectivity of the sections, however high values were observed near the railway station and the eastern limit of the study area. In these areas, in fact, there was a larger resident population, which necessarily generates a greater amount of daily movements.



Fig. 10. Result of the weighted configurational analysis on the Cassino network

4.3 Comparison Between Real and Forecast Data

The data obtained from the Space Syntax forecast model were compared with the pedestrian counts collected in several weekday and pre-holiday days according to the aforementioned analysis periods (Figs. 11 and 12).

The graphs show that the only "unweighted" morphological model derived with a 400 m long metric radius, has fairly good correlation coefficients ranging between around 0.6 and 0.7. While by taking into account the proximity weight, the model returns somehow higher R^2 values, especially for working day pedestrian movements.

In the unweighted scenarios, the outlier points were identified, to understand the reason for these anomalies. These are linked to a large number of pedestrians in some areas of the network characterized by the presence of bus stops, a high concentration of commercial establishments or the presence of schools/universities (Fig. 13).

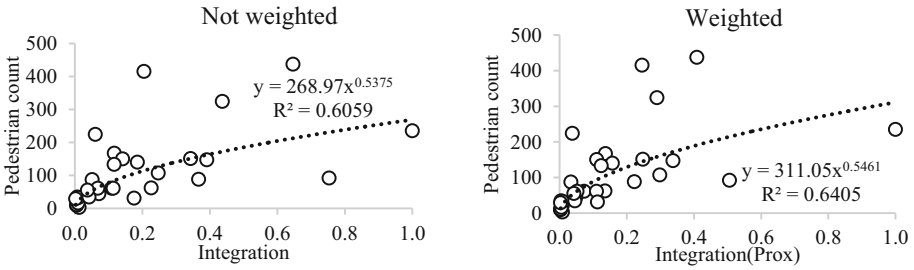


Fig. 11. Pedestrian count versus Integration on the weekday

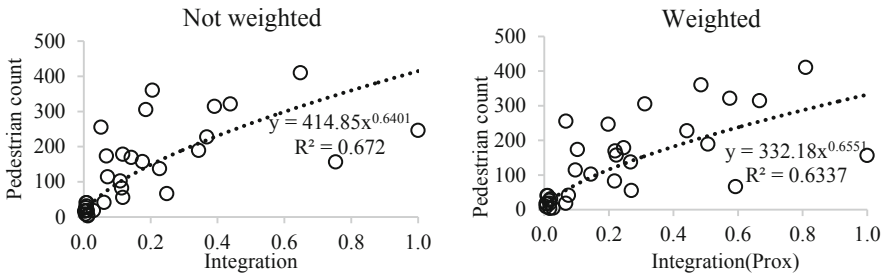


Fig. 12. Pedestrian count versus Integration on the pre-holiday day

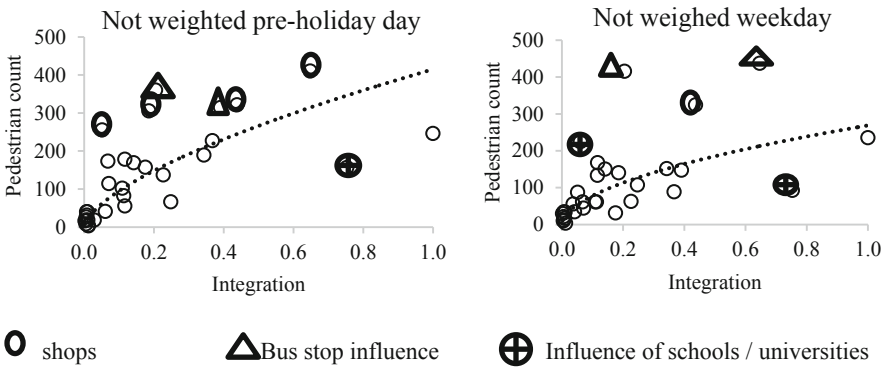


Fig. 13. Pedestrian count versus Integration diagrams with highlighted outliers

By observing these points, it can be argued that the presence of singular "attractors" may be not consistent with the configurational analysis theory and therefore the significant influence of these elements on the pedestrian mobility needs to be separately evaluated. Therefore, the points related to the presence of singular attractors such as educational institutions and bus stops were excluded providing higher R^2 values (Figs. 14 and 15).

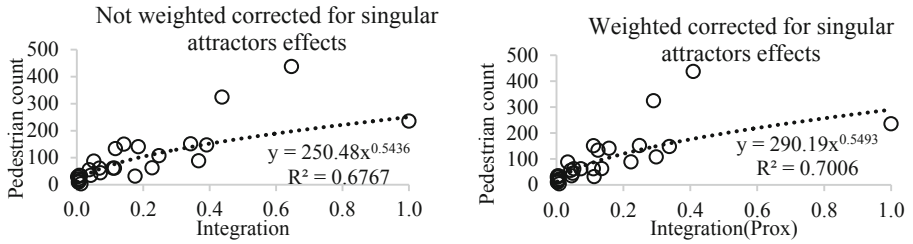


Fig. 14. Pedestrian count versus Integration diagrams without singular pedestrian attractors on the weekday

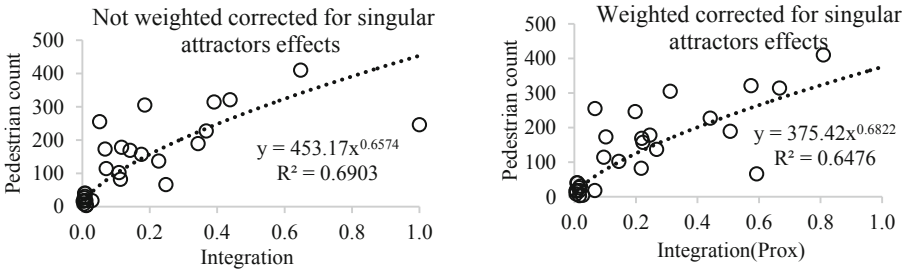


Fig. 15. Pedestrian count versus Integration diagrams without singular pedestrian attractors on the pre-holiday day

It should be noted that by removing the data referring to the singular attractors, results with the "hybrid" approach employing a proximity weight provides fairly satisfactory correlation in the working day scenarios. While in the pre-holiday scenario the values of the correlation coefficient seem slightly lower if compared with those provided by the conventional (unweighted) configurational approach.

It is believed that this may be due to a different walking aptitude in terms impedance function in the pre-holiday scenario for Cassino inhabitants.

5 Conclusions

In this work an original hybrid approach employing a configurational analysis combined with land use and pedestrian mobility aptitude has been proposed and calibrated by means of an experimental pedestrian count campaign carried out in the downtown of Cassino. The ultimate aim of the study is to develop a pedestrian exposure prediction methodology that can help road manager to identify prone-risk area for vulnerable users. Further improvements are expected concerning:

- the increase of the pedestrian counts to improve statistical significance;
- the experimental validation of the proposed methodological approach;
- the extension of the proposed methodology to different urban contexts.

Nonetheless, preliminary results obtained seem somehow promising and allow us to affirm that the hybrid approach developed can provide a satisfactory estimate of pedestrian movements compared to that obtained so far in the scientific literature.

It is believed that the evaluation of the pedestrian movements may constitute a valid support for the study of accident related to vulnerable users in the urban area.

References

1. Al Sayed, K.: Space Syntax Methodology. Bartlett School of Architecture, UCL: London, UK (2018)
2. Ashford, N.M.: Stochastic modelling of passenger and baggage. Traffic Eng. Control **17**, 207–210 (1976)
3. Cervero, R.A.: Travel choices in pedestrian versus automobile oriented neighborhoods. Working Paper 644, University of California at Berkeley, Berkeley, CA (1995)
4. Cutini, V.: Spazio urbano e movimento pedonale. Uno studio sull'ipotesi configurazionale. Cybergeo Eur. J. Geogr. (1999)
5. Dai, W.: A configurational exploration of pedestrian and cyclist movements: using Hangzhou as a case study, China. In: Proceedings of the Ninth International Space Syntax Symposium (2013)
6. Helbing, D.P.: Self-organizing pedestrian movement. Environ. Plann. B: Plann. Des. **28**, 361–383 (2001)
7. Hillier, B., Penn, A.: Natural movement: or configuration and attraction in urban pedestrian movement. Environ. Plann. B: Plann. Des. **20**, 29–66 (1993)
8. Hillier, B., Hanson, J.: Ideas are in things: an application of the space syntax method to descovering house genotypes. Environ. Plann. B: Plann. Des. **14**, 363–385 (1987)
9. Hillier, B.: Network effects and psychological effects: a theory of urban movement. In: International Conference on Spatial Information Theory, pp. 475–490 (2005)
10. Hoogendoorn, S.P.: Pedestrian route-choice and activity scheduling theoryand models. Transp. Res. Part B. **38**, 169–190 (2004)
11. ISTAT. Atti del 9° Censimento generale dell'industria e dei servizi e Censimento delle istituzioni non profit, 5 - Le sezioni di censimento (2015)
12. Kuzmyak, J.R., Walters, J.: NCHRP Report 770 - Estimating Bicycling and Walking for Planning and Project Development: A Guidebook (2014)
13. Jacobsen, P.: Safety in numbers: more walkers and bicyclists, safer walking and bicycling. Injury Prev. **9**, 205–209 (2003)
14. Kitamura, R.M.: A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area. Transportation **24**, 125–158 (1997). https://doi.org/10.1023/A:1017959825565
15. Kurose, S.: A method for identifying accessibility properties of pedestrian shopping networks. J. Retail. Consum. Serv. **2**(2), 111–118 (1995)
16. Landis, B.O.: The Roadside Pedestrian Environment: Toward A Comprehensive Level of Service. Paper 990570, TRB, National Research Council, Washington, D.C. (1999)
17. Leden, L.: Pedestrian risk decrease with pedestrian flow. A case study based on data from signalized intersections in Hamilton. Ontario. Accid. Anal. Prev. **34**, 457–464 (2002)

18. Lerman, Y., Rofè, Y.: Using space syntax to model pedestrian movement in urban transportation planning. Geogr. Anal. **46**, 392–410 (2014)
19. Løvås, G.G.: Modeling and simulation of pedestrian traffic flow. Transp. Res. Part B: Methodol. **28**(6), 429–443 (1994)
20. Raford, N.: Space syntax: an innovative pedestrian volume modeling tool for pedestrian safety. In: Annual Meeting of the Transportation Review Board, Paper 04-2977 (2003)
21. Southworth, M.: The evolving metropolis: studies of community, neighborhood, and street form at the urban edge. J. Am. Plann. Assoc. **59**, 271–287 (1993)