Estimation of Pedestrian Risk Exposure in Urban Areas : Case studies in the US and in France

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ABSTRACT

The paper deals with the estimation of pedestrian risk exposure in urban areas. The approach proposed is based, on the one hand, on a spatial analysis technique called Space Syntax that characterizes the street integration - how streets are connected to each other - which gives rise to a natural movement of persons, and on the other hand, on land-use which acts as a multiplier or a divider of the original flows. Street integration is weighted by factors related to land use to better captures the heterogeneity of street-blocks. The method is applied to two radically different urban spaces: the northern periphery of the University of California at Berkeley (USA) and an area in downtown of Nantes (France). Five land-use factors are used to weight the integration: they express respectively the influence of residential areas, activities, public transportation, presence of sidewalks, and density of active frontage. Counting is performed at different locations and at different periods of the day (morning, lunch time, afternoon). Linear regression is performed between pedestrian volumes and the weighted and unweighted integration. Better correlation is obtained when using the weighted integration. No difference, in terms of correlation, is observed between the periods of the day. The study in Nantes shows that the street side has a significant effect on traffic volume. Discussions are made with respect to the differences between the cities of Berkeley and Nantes and their effect on traffic prediction.

Keywords: Pedestrian, risk exposure, spatial analysis, land-use.

INTRODUCTION

The interpretation of crash statistics should be accompanied by concepts of exposure and risk, where exposure is defined as the number of opportunities for a crash of some type to happen at a specific time-space region, and risk is defined as the probability for a crash of some type to occur in a specific time-space region (Chapman, 1973). Actually, Keall (1995) for example showed that, taking into account the time spent for walking, the collision risk is higher for seniors than for children and teens even if accident records are higher for youth.

Keall and authors like Carré and Julien (2000) use the time or distance for walking or crossing intersections as an indicator of risk exposure. The measurement of this indicator is not easy as it requires surveys and field observations to collect pedestrian trips. Other authors like Raford and Ragland (2004) use instead pedestrian volumes to estimate risk exposure. Researchers at University College of London have developed a set of methods called Space Syntax to study how urban streets designs affect pedestrian displacements (Penn et al., 1998). Space Syntax appears then as an attractive way to predict pedestrian volume from the knowledge of urban street network (concept of street integration developed in subsequent sections).

It is also well known that land use affects pedestrian activity. A range of land-use characteristics are used to predict pedestrian volume at intersections (Pulugurtha et al., 2006; Schneider et al., 2009). Integration and land-use rely on each other and describe complementary parts of the complexities of a city. Actually, the urban morphology creates a "natural" first movement of pedestrians (Penn and Dalton, 2004), which in turn, attracts more activities and transit opportunities along the main arterials. In turn, the presence of activities and the accessibility to transit amplify the pedestrian traffic. Based on these observations, it seems that incorporating Space Syntax and land-use in a complementary manner would be beneficial.

In this paper, work towards developing a weighting mechanism for Space Syntax using land-use variables is described. The approach is different from those that can be found in previous publications (using Space Syntax' indicators and land-use characteristics as independent variables in a regression analysis) (Cutini, 2001; Stonor et al., 2002; Desyllas et al., 2003; Raford and Ragland, 2004). The present method is inspired instead by predictive models for pedestrian crashes described in Harwood et al. (2008). The paper serves the purpose of demonstrating the potential of the novel approach. In the subsequent section we introduce the proposed weighting mechanism, and describe the data collected to demonstrate its potential. The results are presented next, followed by a discussion of the implications of the findings and future research goals.

BACKGROUND

The proposed approach assumes that Space Syntax provides an average for pedestrian activity at the street level. Land-use variables, at the block level, are then used as simple weights to increase or decrease the initial value of integration. This way the integration determined initially for a street can vary from one block to another depending on its land use. The following sections provide basics about Space Syntax and a description of predictive models for pedestrian crashes.

Urban morphology

To characterize the street distribution, Space Syntax defines open spaces that are blocks bounded by the streets surrounding them. Lines that are an axial representation of the space cross these spaces. The axial representation is then converted into a graph where each line (street) is depicted as a "node" and each intersection between the lines is represented by a "link." Teklenburg et al. (1993) provide a detailed description of the mathematical formulas used to calculate indicators of Space Syntax characterizing the arrangement of streets, specifically integration:

- the Total Depth (TD_i) of node (i) expresses the number of links between node (i) and all other network nodes. When the total number of nodes (n) is high, as is for cities, TD_i increases quickly and using the "Mean Depth" (MD_i) of node (i) is preferred:

$$MD_i = \frac{TD_i}{n-1} \quad (1)$$

- the Relative Asymmetry (RA_i) of node (i) is expressed as:

$$RA_i = 2\left(\frac{MD_i - 1}{n-2}\right) \quad (2)$$

- the integration parameter (Int_i) is the inverse of RA_i:

$$Int_i = \frac{1}{RA_i} \quad (3)$$

It has been shown that the best correlation between Space Syntax parameters and pedestrian volume were obtained with integration radius 3, denoted Int[3] (Penn et al., 1998). The term "radius" is not related to a distance but rather a number of links; this means that for a given node, we take into account in the calculations nodes accessible in less than three (≤ 3) links. In the following sections, as the radius is always less than 3, the symbol "[3]" is not used to simplify the formulae.

Predictive models for pedestrian crashes

Predictive models for pedestrian crashes can be written under the following general form (Harwood et al., 2008):

$$N_{ped} = \exp\left(\beta_0 + \beta_1 ADT + \beta_2 PedVol + \sum_{i=3}^{n} \beta_i X_i\right) \quad (4)$$

where:
N_{ped}: expected number of pedestrian crashes;
ADT: annual average daily traffic (i.e., vehicular volume);
PedVol: annual average daily pedestrian volume;
X_i (i = 3, n): other site characteristics such as proportion of left-turn volume, number of lanes, speed limit, presence/absence of a crosswalk, and presence/absence of a median;
β_i (i = 1, n): coefficients to be estimated.

As land-use affects pedestrian safety, the number of crashes in Equation (4) has to be multiplied by accident modification factors (AMF), meaning that N_{ped} should be modified as follows:

$$N_{ped} = \prod_{j=1}^{m} AMF_j . \exp\left(\beta_0 + \beta_1 ADT + \beta_2 PedVol + \sum_{i=3}^{n} \beta_i X_i\right) \quad (5)$$

where:
AMF_j: accident modification factor associated to land-use characteristics (j).

For the case of the cities of Toronto (Canada) and Charlotte (USA), three land-use characteristics are considered (Harwood et al., 2008):

- number of bus stops within 300m of the intersection;
- presence of schools within 300m of the intersection;
- number of alcohol sales establishment within 300m of the intersection.

Values of AMFs are obtained empirically. Moreover, the use of AMFs products assumes that their effects are independent.

METHODOLOGY

The street network is first analyzed using Space Syntax. Values of Int_i are then multiplied by five factors noted λ_j (j = 1,..,5) expressing respectively:

- λ_1 - the influence of residential areas.
  Pedestrian traffic in residential areas has been shown to be lower than expected from integration value (Penn et al., 1998).
- λ_2 - the influence of activities (stores, movies, offices, schools, etc.).
  These activities have been shown to generate pedestrian traffic (Cutini, 2001; Shin et al. 2007; Kim and Sohn, 2002). However, there is no differentiation between the different activity types because there are not enough results in the literature indicating the weight of each activity type on pedestrian movement.
- λ_3 - the influence of public transportation.
  Access to transit is associated with travel by foot (Stonor et al., 2002).
- λ_4 - the influence of sidewalks on pedestrian traffic.
  The absence of sidewalk can reduce the pedestrian traffic (Desyllas and Duxbury, 2001).
- λ_5 - the influence of active frontage.
  Blank wall locations that have either very few or no retail active frontages should have their integration values reduced by a consistent factor (Stonor et al., 2002).

The factors (λ) are similar the AMFs factors used in pedestrian crashes models. To a large extent, these factors are independent and it can be reasonably assumed that they have a multiplicative effect on street integration.
Land use data are used to evaluate the dominant features of each block in a study area. Table 1 below describes the criteria and the empirical values assigned for each of the factors (λ). When the five land-use features do not dominate, the corresponding weighting factor takes the value of 1 (no modification of integration).

Table 1. Criteria for Assigning the Integration Weights

Factor	Value	Criteria	Effect
λ_1	0.5	Street block population density > 10,000 / km^2	Reduction effect
λ_2	2	# of stores > 10	Attraction effect
λ_3	2	# of operational transit stops > 20/day	Attraction effect
λ_4	0.5	incomplete sidewalk	Reduction effect
λ_5	0.5	Predominantly "blank" (parking lot, wall, etc.)	Reduction effect
	2	Heavily occupied by activities	Attraction effect

EXPERIMENTS

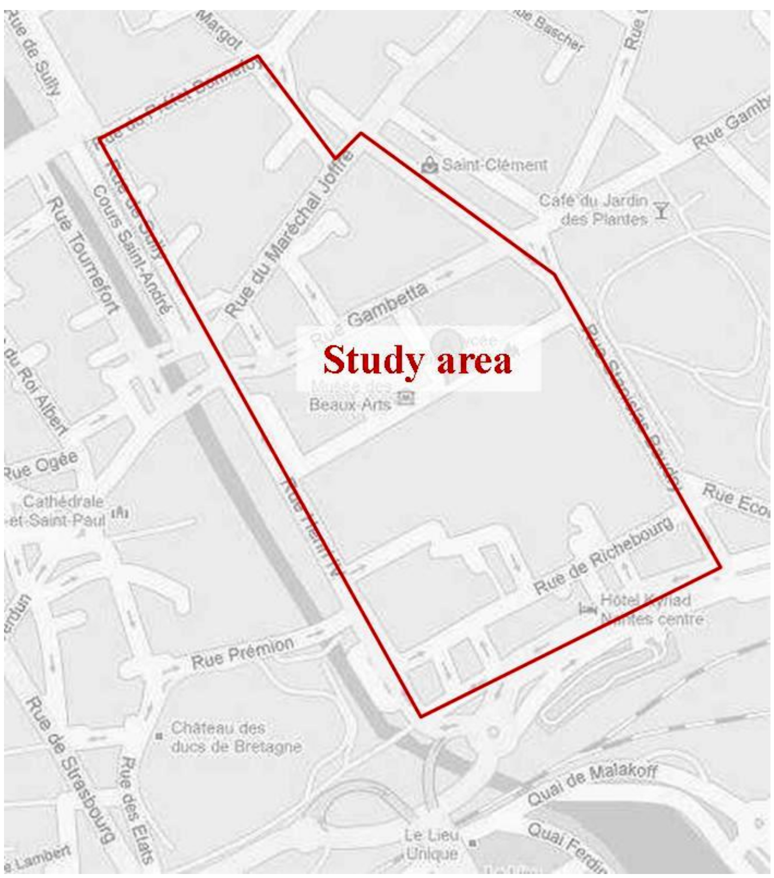
Study areas

Two study areas were chosen respectively at the cities of Berkeley (USA) and Nantes (France). The objective is twofold: i) one area – in Berkeley – is used for the calibration of the weighting factors (mainly the criteria used to evaluate the dominant features, see Table 1), and the other – in Nantes – for the validation of the proposed weighted values; ii) application of the proposed method to different street networks – US and Europe – helps to evaluate the robustness of the proposed weighted values.

City of Berkeley (USA)

The study area is the northern periphery of the University of California at Berkeley. The area is bounded on the north by Virginia Street, south by Hearst Avenue, east by La Loma Avenue and west by Oxford Street as shown in Figure 1a. This area was chosen since it has moderate pedestrian activity and consists of many different land-use types such as residential, commercial, academic, etc.

a)



b)

Figure 1. Study area maps (a: North periphery of UC Berkeley; b: Clemenceau area in Nantes)

City of Nantes (France)

The study area is centered on Clemenceau high school in downtown of Nantes (Figure 1b) with many displacement attractors like the high school, the Fine Arts Museum as well as the commercial Gambetta street.

Pedestrian count

The counting method is derived from that recommended for Space Syntax analysis by Desyllas and Duxbury (2001). It consists of midblock counting pedestrians crossing a virtual line in front of the observer (Figure 2) for 5-minute intervals.

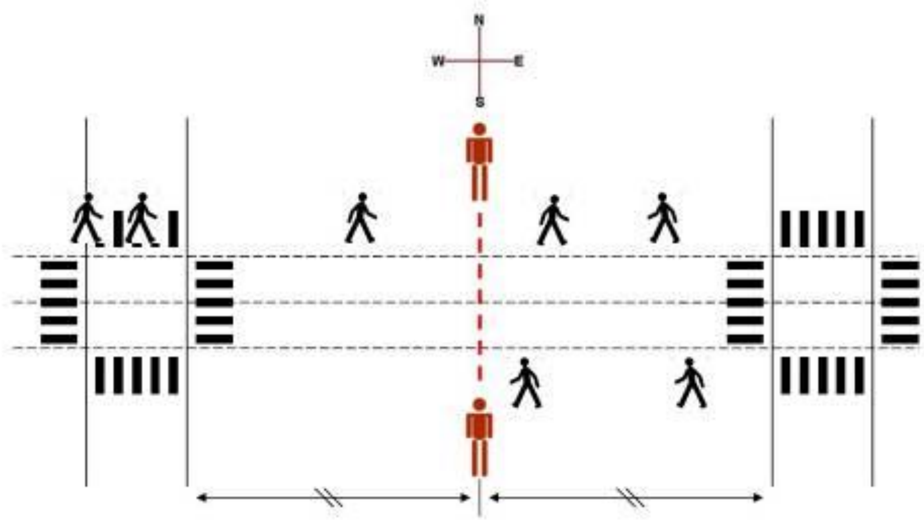


Figure 2. Location of a stationary observer and virtual gate

Respectively 15 and 17 observation points (gates) were selected in Berkeley and Nantes and their location is shown in Figure 3. At each gate, counting is done simultaneously on opposite sidewalks of the street by two observers (points ● and ● in Figure 3). Each observer counts passing pedestrians for 5 minutes (red line in
Figure 2) and specifies the direction of movement relative to the four cardinal directions (North, South, East, and West). Observers then move to the next gate in the direction indicated by the route numbers of the gates (Figure 3). The number of gates enables to complete all gates within two hours. The numbering of gates gives the sense of journey made by observers and aims to minimize the transfer time from one gate to another.
Counting is made over three periods: 8:30 a.m. –10:30 a.m., 11a.m. –1 p m , and 4 p.m. – 6 p.m. The aggregate observation duration (six hours) is shorter than what is usually seen in the literature (ten hours). Nevertheless, the chosen periods are representative of pedestrian traffic (office hours, classes, lunch break, etc.).

a)
b)


Figure 3. Location of pedestrian counting points (a: Berkeley; b: Nantes)

RESULTS

Case of the city of Berkeley

<u>Pedestrian count</u>

For streets that have more than one observation point (gate), the number of pedestrians crossing for the different gates were plotted (Figure 4). Note that since counts can not be made concurrently, the comparison assumes that pedestrian volumes are stationary and do not fluctuate significantly during the counting period of that street. Since the time between two successive gates, is about 8 minutes (5 min. count and ~3 min. to transfer), this comparison is reasonable.
Figure 4 shows that the pedestrian volumes can vary from one gate to another (gates 1 to 5 on Hearst, Figure 4), and even from one side of the block to another (gate 2, and to a lesser degree gate 4, on Hearst Avenue, Figure 4). The last observation corroborates that made by Desyllas and

Duxbury (2003). The fact that pedestrian volume changes along a same street (same integration based on Space Syntax analysis) proves the need to modify integration as a function of block activity.

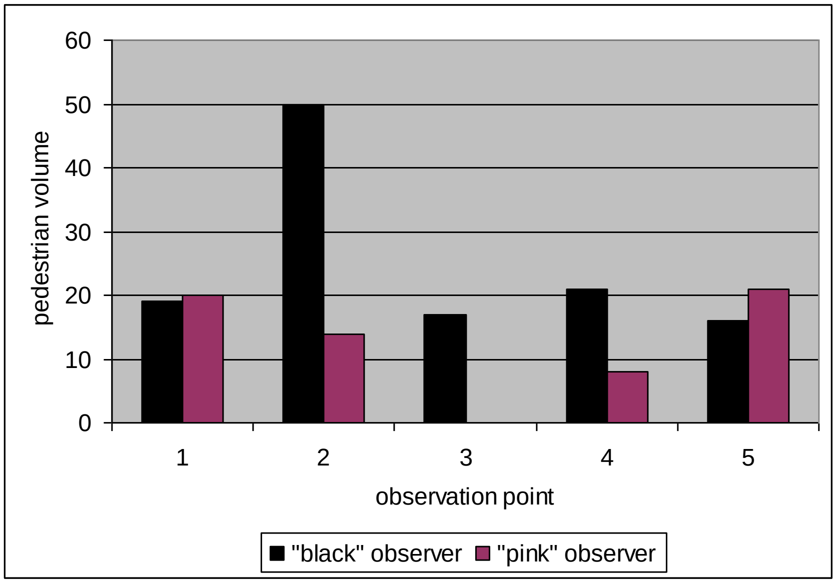


Figure 4. Variation in pedestrian volumes (case of Hearst avenue in Berkeley)

Integration

The results of the Space Syntax analysis are summarized in Table 2 and Figure 5 (colors range is red-orange-yellow-green-blue-purple for integration ranging respectively from high to low). The axial presentation as well as the calculation of Space Syntax parameters were performed by means of the free-on-line AGRAPH software (Manum et al., 2010). It can be seen that all the streets which are horizontal to campus are well integrated. Note that the size of the study area limits the number of links (intersections) between nodes (streets) to 3 at most. The calculate integration parameter is therefore automatically of radius 3.

Table 2. Space Syntax parameters for the North Periphery of UC Berkeley

Street	Total Depth	Mean Depth	Relative Asymmetry	Integration
Hearst	12	1.200	0.044	22.5
Ridge	17	1.700	0.156	6.4
Le Conte	13	1.300	0.067	15.0
Virginia	13	1.300	0.067	15.0
Oxford	19	1.900	0.200	5.0
Spruce	19	1.900	0.200	5.0
Arch	17	1.700	0.156	6.4
Scenic	16	1.600	0.133	7.5
Euclid	16	1.600	0.133	7.5
Le Roy	16	1.600	0.133	7.5
La Loma	16	1.600	0.133	7.5

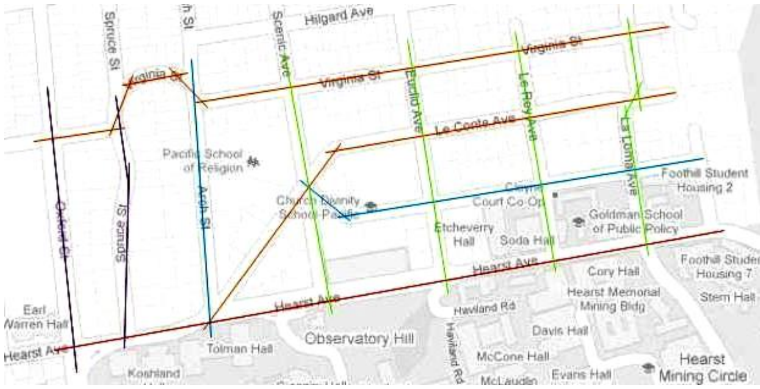


Figure 5. Integration for the North Periphery of UC Berkeley

Figure 6 shows the relationship between integration and pedestrian volumes. Each point represents a single observation. There are roughly three levels of integration while pedestrian traffic varies much more. Figure 6 does not demonstrate any pattern that defines a relationship between integration and pedestrian volumes. This result is not surprising and compared to those found in the literature. This strengthens instead the notion that predicating pedestrian activity based on integration is limited for certain locations.

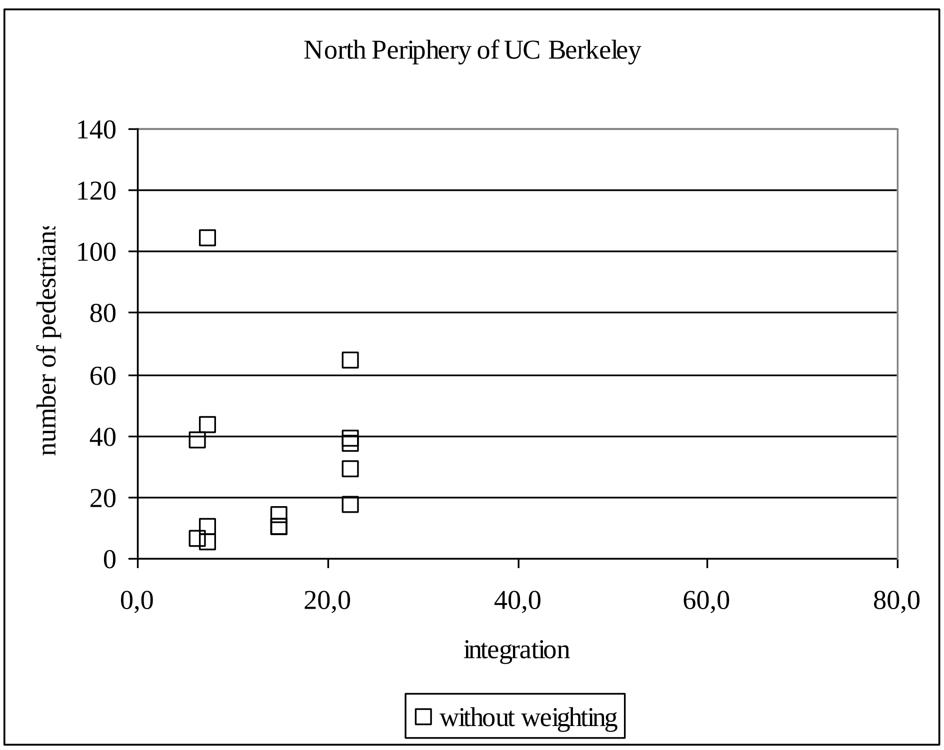


Figure 6. Relationship between integration and pedestrian volumes - North Periphery of UC Berkeley

Weighted integration

Table 3 summarizes the assigned weights and the data used to derive them.

Table 3. Land-use related weights for the North Periphery of UC Berkeley

Gate	Street	λ_1 habitation	λ_2 activities	λ_3 Transit	λ_4 sidewalk	λ_5 active frontage
1	Hearst	0.5	1	2	1	0.5
2	Hearst	1	1	2	1	0.5
3	Hearst	1	1	2	0.5	0.5
4	Hearst	0.5	1	1	0.5	1
5	Hearst	1	1	2	1	0.5
6	Arch	0.5	1	1	1	1
7	Le Conte	0.5	1	1	1	1
8	Scenic	0.5	1	1	1	1
9	Virginia	0.5	1	1	1	1
10	Virginia	0.5	1	1	1	1
11	Le Conte	0.5	1	1	1	1
12	Euclid	1	2	2	1	2
13	Ridge	0.5	1	1	1	1
14	Le Roy	0.5	1	1	1	0.5
15	La Loma	0.5	1	1	1	1

The relationship between weighted integration, taking into account the influence of land use, and the pedestrian volumes is shown in Figure 7. The regression line results in a high correlation coefficient of 0.72. Improvement can be seen compared with the Figure 6 even if the sample size (15 points) and the presence of one point at high pedestrian volume and high weighted integration ask for further investigation to confirm this first tendency.

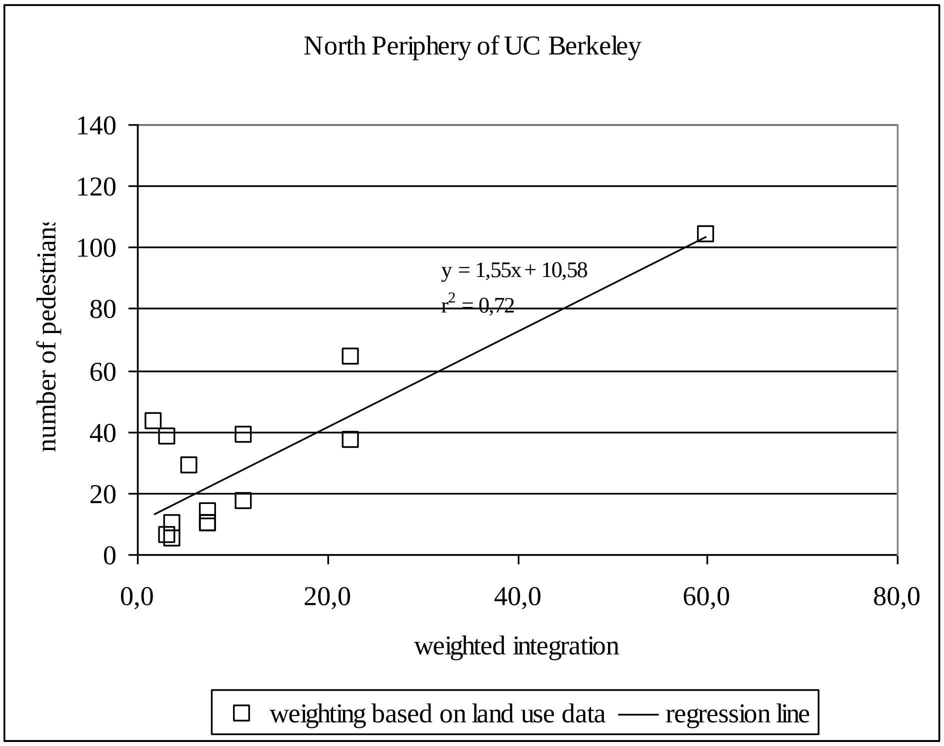


Figure 7. Relationship between weighted integration and pedestrian volume - North Periphery of UC Berkeley

Case of the city of Nantes

Integration

The results of the Space Syntax analysis are summarized in Table 4 and Figure 8 (produced by AGRAPH software).

Table 4. Space Syntax parameters for the Clemenceau area in Nantes

Street	Total Depth	Mean Depth	Relative Asymmetry	Integration
Clemenceau	39	2.167	0.137	7.3
Gambetta	34	1.889	0.105	9.6
Joffre	37	2.056	0.124	8.1
Bonnefoy	44	2.444	0.170	5.9
Richebourg	34	1.889	0.105	9.6
Charcot	35	1.944	0.111	9.0
Sully-Henri IV	29	1.611	0.072	13.9
Refoulais	39	2.167	0.137	7.3
Baudry	33	1.833	0.098	10.2

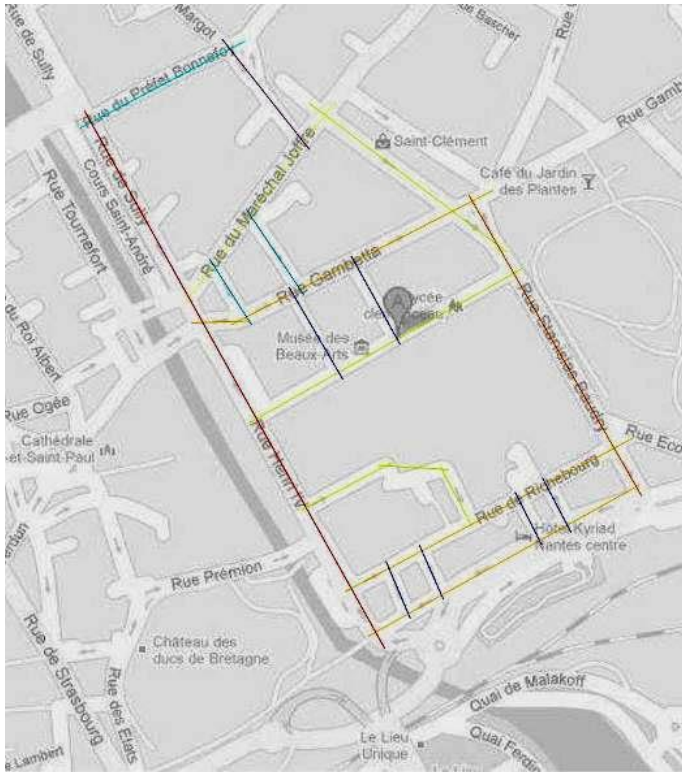


Figure 8. Integration for the Clemenceau area of Nantes

Figure 9 shows the relationship between integration and pedestrian volumes. As in the case of Berkeley, there is no pattern that defines a relationship between integration and pedestrian volumes.

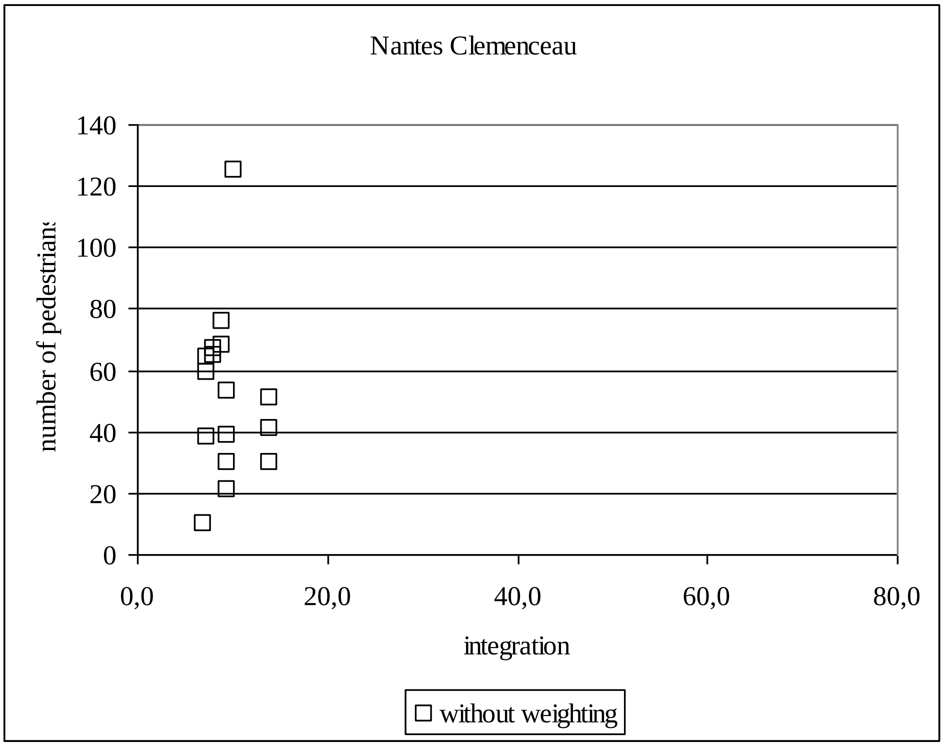


Figure 9. Relationship between integration and pedestrian volumes - Clemenceau area in Nantes

<u>Weighted integration</u>

Table 5 summarizes the assigned weights and the data used to derive them.

Table 5. Land-use related weights for the Clemenceau area in Nantes

Gate	Street	λ_1 habitation	λ_2 activities	λ_3 transit	λ_4 sidewalk	λ_5 active frontage
1	Sully	0.5	1	1	1	1
2	Joffre	1	2	1	1	2
3	Joffre	1	2	1	1	2
4	Refoulais	1	1	1	1	0.5
5	Baudry	0.5	1	1	1	1
6	Baudry	1	2	2	1	0.5
7	Richebourg	0.5	1	1	1	1
8	Charcot	1	2	2	1	2
9	Charcot	1	2	2	1	2
10	Richebourg	0.5	1	1	1	1
11	Henri IV	0.5	1	2	1	1
12	Malherbe	0.5	1	1	1	1
13	Henri IV	0.5	1	2	1	1
14	Clemenceau	0.5	1	1	1	1

Gate	Street	λ_1 habitation	λ_2 activities	λ_3 transit	λ_4 sidewalk	λ_5 active frontage
15	Clemenceau	0.5	1	1	1	1
16	Gambetta	0.5	1	1	1	1
17	Gambetta	1	1	1	1	0.5

The relationship between weighted integration, taking into account the influence of land use, and the pedestrian volumes is shown in Figure 10. Tendency can be seen even if the scatter is high. It can be noticed that if the point surrounded in red – gate n° 6 – is removed, the correlation coefficient r^2 jumps to 0.45. The number of pedestrians passing gate 6 is high as people travel to and from the main train station situated south of gate 8 (Figure 3b). As this attractor is not included in the studied area, the analysis is biased.

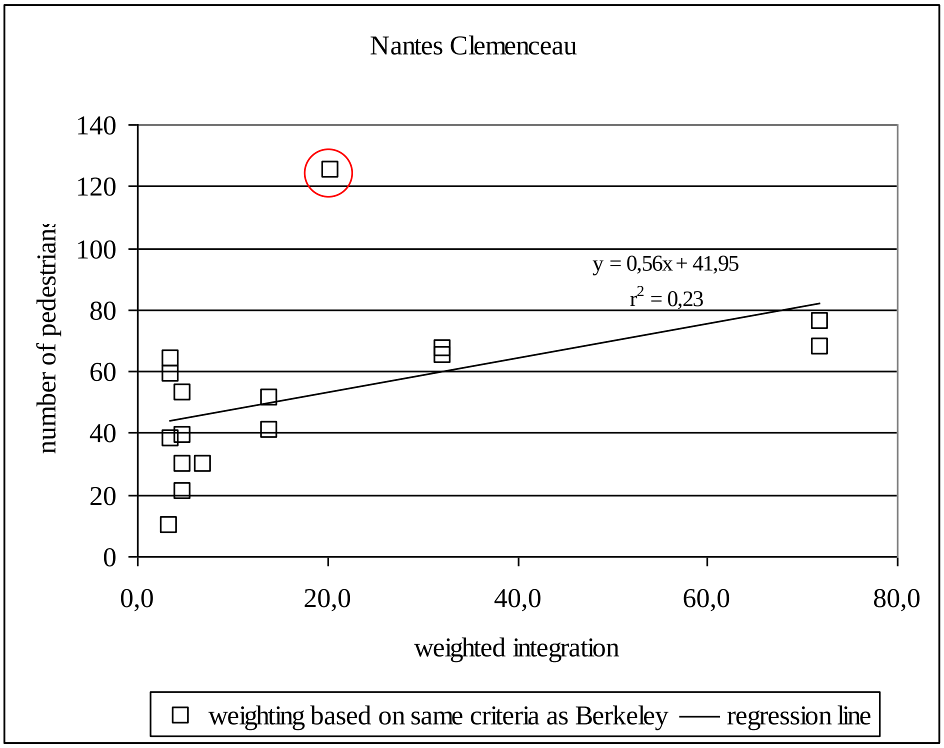
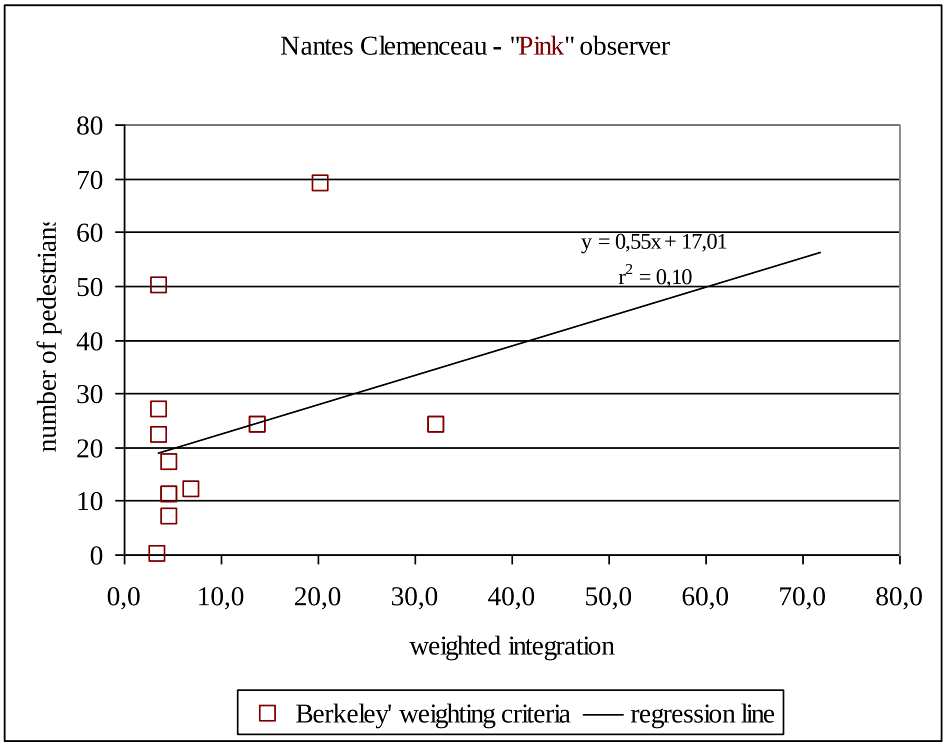
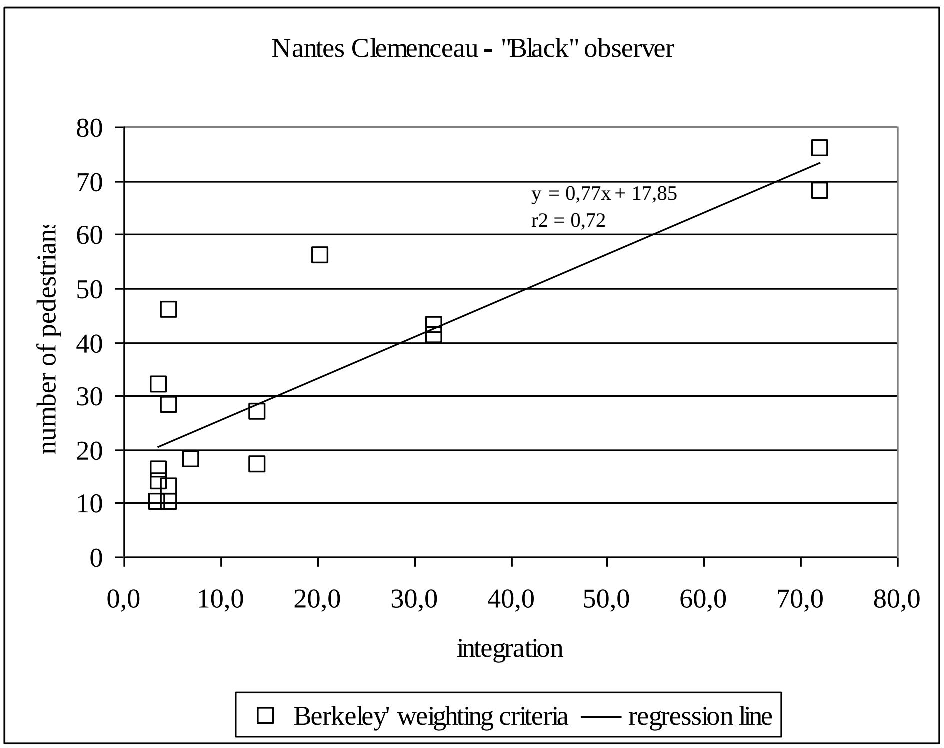


Figure 10. Relationship between weighted integration and pedestrian volume - Clemenceau area in Nantes

As the exam of the counting at different periods of the day does not reveal any relevant explanation with respect to the scatter in Figure 10, it was decided to examine separately the counting performed by “black” and “pink” observers. Figure 11 shows that while there is no observable tendency between weighted integration and the pedestrian volume counted by the pink observer (Figure 11a), a much better correlation is obtained with data collected by the black observer (Figure 11b). For the time being, no relevant explanation can be found to interpret results of Figure 11. Nevertheless, it can be said that the sidewalk’ effect is not negligible, based on results in Nantes.



a)



b)

Figure 11. Sidewalk' effect on the relationship between weighted integration and pedestrian volume (Clemenceau area in Nantes)

CONCLUSIONS

In this paper, work towards developing a weighting mechanism for Space Syntax using land-use variables is described. The approach is different from those that can be found in previous publications (using Space Syntax' indicators and land-use characteristics as independent variables in a regression analysis). The present method is inspired instead by predictive models for pedestrian crashes and serves the purpose of demonstrating the potential of the novel approach.

The integration provided by Space Syntax analysis is considered as an average for a street. Integration values for each block are then modified by five factors related respectively to the presence of habitations, activities (stores, offices, schools, etc.) in terms of number and density, transits and sidewalks. Criteria are defined to evaluate the dominant features. Empirical values are assigned to the factors. Two study areas were chosen to assess the feasibility of the method: the North periphery of UC Berkeley campus and an area in downtown of Nantes centered on Clemenceau high school. Pedestrians are counted at different locations and periods of the day. Regression between pedestrian volume and integration shows that no pattern is observed without weighting and fair tendency is obtained with weighted integration. The study in Nantes shows further that the analysis of pedestrian volume should be done at the street side level.

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