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1 **WEIGHING INTEGRATION BY BLOCK HETEROGENEITY TO**
2 **EVALUATE PEDESTRIAN ACTIVITY**

3
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1 ABSTRACT

2 Pedestrian exposure is a necessary component for a meaningful evaluation of pedestrian safety.
3 The Space Syntax approach has a track record of accurate prediction of pedestrian activity by
4 estimating the physical street connectivity in urban environments. However, for some
5 environments, the performance of Space Syntax is limited and cannot be used as a reliable
6 estimate of exposure. This paper makes use of the interdependency between: (i) street
7 connectivity - estimated here using *integration*; and (ii) land-use characteristics; to propose a
8 mechanism to adjust *integration* by land-use features at the block level. Different levels of
9 *integration* for each street-block, which hold the same mean values along the same street, are
10 weighted based on dominant land-use features. The *weighted integration* value for a street-block
11 dominated by commercial property is higher than the mean *integration* value for that street.
12 Conversely, the *weighted integration* value for a residential street-block is lower than the mean
13 *integration* value for that street. The proposed approach captures the heterogeneity of street-
14 blocks, which is not always captured by Space Syntax. Applying this method to the northern
15 periphery of the University of California, Berkeley, has produced promising preliminary results.
16 It was shown that the *weighted integration* values (at the street-block level) are better correlated
17 with pedestrian volumes than mean *integration* values (street scale). Further research efforts are
18 required to develop this simplified approach into a pedestrian exposure prediction model.

19 *Key words:* pedestrian volumes, weighted integration, street-block, land-use.

20

1 BACKGROUND

2 The interpretation of crash statistics should be accompanied by concepts of *exposure* and *risk*
3 (*1*). Where *exposure* is defined as the number of opportunities for a crash of some type to happen
4 at a specific time-space region, and *risk* is defined as the probability for a crash of some type to
5 occur in a specific time-space region. In light of this, to estimate the *risk* for pedestrians it is
6 necessary to control the absolute number of crashes by pedestrian *exposure* using pedestrian
7 prediction models. Since urban streets are not homogenous it is important to study how different
8 designs affect safety and therefore necessary to obtain *exposure* data at the block level.

9 Space Syntax theory (*2, 3*) uses spatial and structural descriptions to simplify the
10 complexities of cities, and has played a central role in providing insights regarding pedestrian
11 movement dynamics. Space Syntax also has a track record of high accuracy predicting pedestrian
12 activity within streets in urban environments. It uses *integration* as a measure of accessibility,
13 based on the spatial configuration of urban spaces (*4, 5*).

14 Predicting pedestrian activity using land-use data has also been shown to produce reliable
15 results (*6, 7*). The assumption here is that land-use features serve as pedestrian attractors and can
16 predict pedestrian activity. In situations where the spatial configuration is not sufficient to predict
17 pedestrian activity, a range of land-use characteristics are used to complement integration by
18 applying a multivariate regression analysis (*8, 9, 10, 11*). This association is necessary because
19 the urban morphology creates a “natural” first movement of pedestrians (*5*), which in turn,
20 attracts more activities and transit opportunities along the main arterials. In turn, the presence of
21 activities and the accessibility to transit amplify the pedestrian traffic. Therefore, integration and
22 land-use rely on each other and describe complementary parts of the complexities of a city.
23 Based on these observations, it seems that incorporating Space Syntax and land-use in a
24 complementary manner would be beneficial.

25 It is important to emphasize that this manuscript describes preliminary work towards
26 developing a weighting mechanism for Space Syntax using land-use variables, and does not
27 claim a prediction model. It therefore serves the purpose of demonstrating the potential of such
28 an approach.

29 In the subsequent section the proposed weighting mechanism is introduced, and the
30 collected data is describe to demonstrate its potential. The results are presented next, followed by
31 a discussion of the implications of the findings and future research goals.

33 METHOD

34 The proposed approach assumes that *integration* estimates an initial average for pedestrian
35 activity at the street level, for a modeled region. Land-use variables, at the block level, are then
36 used as simple weights to increase or decrease the initial value of integration. This way the
37 *integration* determined initially for a street can vary from one block to another depending on its
38 land use.

40 Urban Morphology

41 To characterize the street distribution, Space Syntax defines open spaces that are blocks bounded
42 by the streets surrounding them. Lines that are an axial representation of the space cross these
43 spaces. A simple representation consisting of plotting the lines corresponding to the streets was
44 applied using the AGRAPH software (*12*). The axial representation is then converted into a
45 graph where each line (street) is depicted as a “node” and each intersection between the lines is
46 represented by a “link.” Manum provides a detailed description of the mathematical formulas

1 used to calculate indicators of Space Syntax characterizing the arrangement of streets,
2 specifically *integration* (13):

- 3 1. The *Total Depth* (TD_i) of node i expresses the number of links between node i and all
4 other network nodes. When the total number of nodes, n , is high, as is for cities, TD_i
5 increases quickly and using the "Mean Depth" (MD_i) of node i is preferred:
6

$$MD_i = \frac{TD_i}{n - 1}$$

7
8 MD_i is then normalized to be between 0 and 1, where higher values represent a more
9 integrated node.

- 10 2. The *Relative Asymmetry* (RA_i) of node i is express as:
11

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

- 12
13 3. The *integration* parameter (Int) is the inverse of RA_i :
14

$$Int = \frac{1}{RA_i}$$

15
16 It has been shown that the best correlation between Space Syntax parameters and
17 pedestrian volume were obtained with *integration* radius 3, denoted $Int[3]$ (14). The term
18 "radius" is not related to a distance but rather to the number of links, this means that for a given
19 node, we take into account in the calculations nodes accessible in less than three (≤ 3) links.
20

21 **Weighted Integration**

22 The method presented hereafter is designed to locally modify the $Int[3]$ of a street to reflect
23 block heterogeneity with respect to activities that influence pedestrian movement. In this study,
24 for each observation point, the value of the $Int[3]$ is multiplied by five factors noted λ_i ($i =$
25 $1, \dots, 5$):
26

- 27 • λ_1 - the influence of residential areas.
28 Pedestrian traffic in residential areas has been shown to be lower than expected from
29 integration value (14).
- 30 • λ_2 - the influence of activities (stores, movies, offices, schools, etc.).
31 These activities have been shown to generate pedestrian traffic (8,15,16). However, there
32 is no differentiation between the different activity types because there are not enough
33 results in the literature indicating the weight of each activity type on pedestrian
34 movement.
- 35 • λ_3 - the influence of public transportation.
36 Access to transit is associated with travel by foot (10).
- 37 • λ_4 - the influence of sidewalks on pedestrian traffic.
38 The absence of sidewalk can reduce the pedestrian traffic (17).
- 39 • λ_5 - the influence of active frontage.

Blank wall locations that have either very few or no retail active frontages should have their Footway Accessibility (i.e., *integration*) values reduced by a constant factor (10).

To a large extent, these factors are independent and therefore the assumption that these factors have a multiplicative effect on $Int[3]$ is reasonable. For example, if an observation point is located in a shopping area with numerous public transportation stops, the weighted value, $WInt[3]$, would be: $\lambda_3 \lambda_2 Int[3]$. When the five land-use features do not dominate, the corresponding weighting factor takes the value of 1 (no modification of $Int[3]$). 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 values assigned for each of the factors.

TABLE 1. Criteria for Assigning the Integration Weights

Factor	Value	Criteria	Effect
λ_1	0.5	Street block population density > 10,000 / m 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
λ_5	2	Heavily occupied by activities	Attraction effect

Study Area

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 1. This area was chosen since it has moderate pedestrian activity and consists of many different land-use types such as residential, commercial, academic, etc.



FIGURE 1. Study Area Map

Pedestrian Counts

The counting method is derived from that recommended for Space Syntax analysis by Desyllas and Duxbury (17). It consists of midblock counting pedestrians crossing a virtual line in front of the observer (

FIGURE 2) for 5-minute intervals. The observations were made on two different days: May 3, 2011 and May 19, 2011, which are both after the Spring 2011 semester has ended, and don't represent a typical week. However, since the purpose of this experiment is not a prediction it was not necessary to select a typical week.

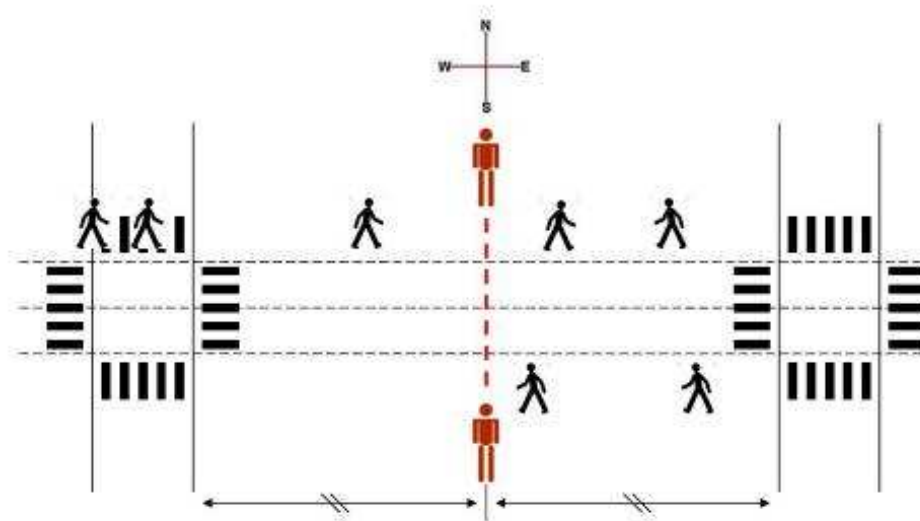


FIGURE 2. Location of a Stationary Observer and Virtual Gate

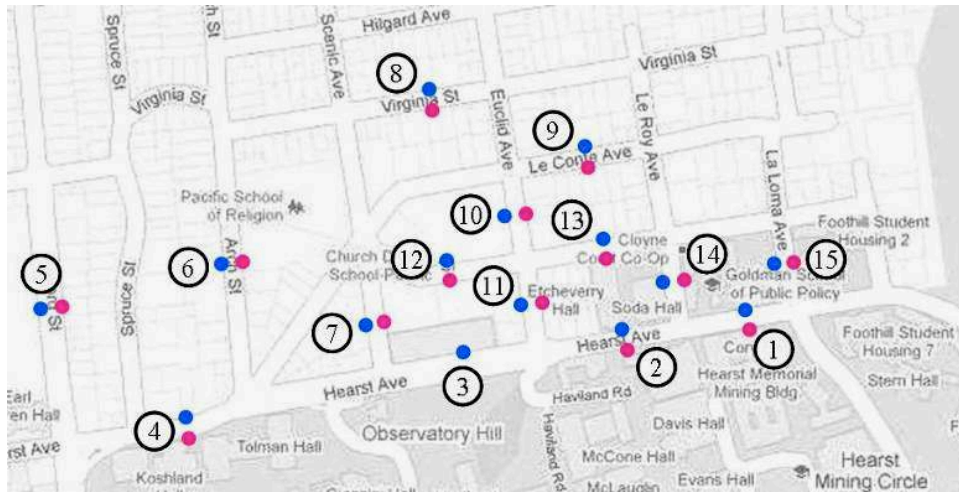
1 On May 3, 2011, counts are made over three periods: 8:30 a.m. –10:30 a.m., 11 a.m. –1 p.m., and
2 4 p.m. – 6 p.m. The aggregate observation duration (six hours) is shorter than what is usually
3 seen in the literature (ten hours). Nevertheless, the chosen periods are representative of
4 pedestrian traffic (office hours, classes, lunch break, etc.). Fifteen observation points (gates)
5 were selected and their location is shown in **FIGURE 3**. On the second counting day (May 19,
6 2011), some observation points of the previous day—mostly those located in residential areas—
7 were moved to more crowded places like Euclid avenue to study the block variation of
8 pedestrian traffic.

9 At each gate, counting is done simultaneously on opposite sidewalks of the street by two
10 observers (points • and • in **FIGURE 3**). Each observer counts passing pedestrians for 5 minutes
11 (red line in

12 **FIGURE 2**) and specifies the direction of movement relative to the four cardinal
13 directions (North, South, East, and West). Observers then move to the next gate in the direction
14 indicated by the route numbers of the gates (1 to 15, Figure 3). The number of gates (15 in total)
15 enables to complete all gates within two hours. The numbering of gates gives the sense of
16 journey made by observers and aims to minimize the walking time from one gate to another.
17



(a) Day 1 - 3/5/2011



(b) Day 2 - 3/5/2011

FIGURE 3. Location of Pedestrian Counts

RESULTS

Pedestrian Counts

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 may also vary from one side of the block to another (gate 2, and to a lesser degree gate 4, on Hearst Avenue, FIGURE 4a) and from one observation point to another (gates 1 and 2 on Hearst, FIGURE 4a; gates 10 and 11, FIGURE 4b).

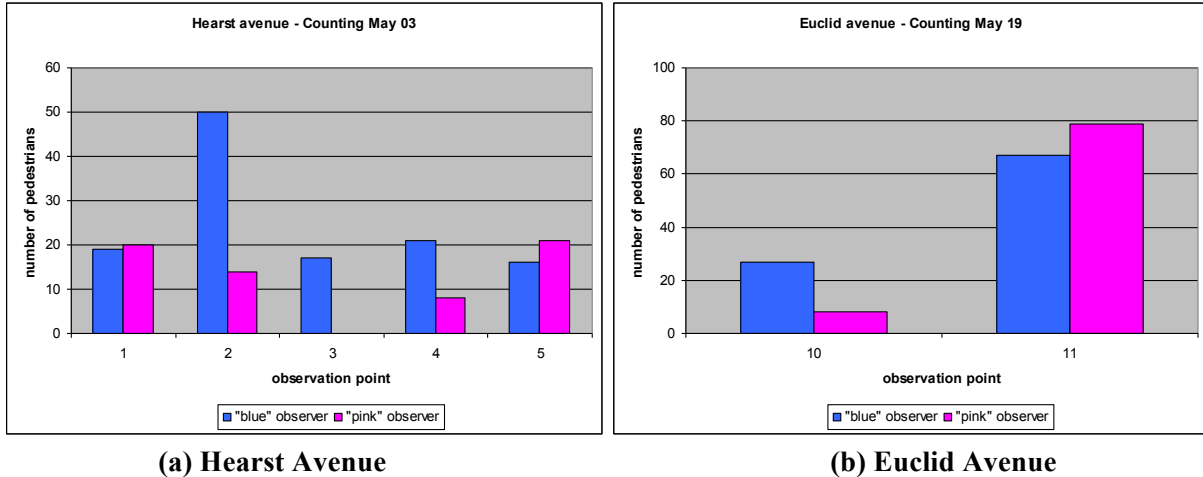


FIGURE 4. Variation in Pedestrian Volumes

For the variation of traffic at gate 2 (FIGURE 4a), the explanation comes from the presence of two buildings Soda Hall (Electrical and Computer Engineering) and Etcheverry Hall (Mechanical Engineering) on the North side (“blue” observer) that allow more student to leave classes than all other buildings on the South side (“pink” observer). For the traffic variation between gates 10 and 11 of Euclid (FIGURE 4b), the explanation comes from the difference of space occupation between gate 11’s block (restaurants, shops) and gate 10’s block (virtually no land use) (FIGURE 5). The influence of the land use is evident here as the block length is relatively short (about 70m), and one would assume that traffic is the same between gates 10 and 11.

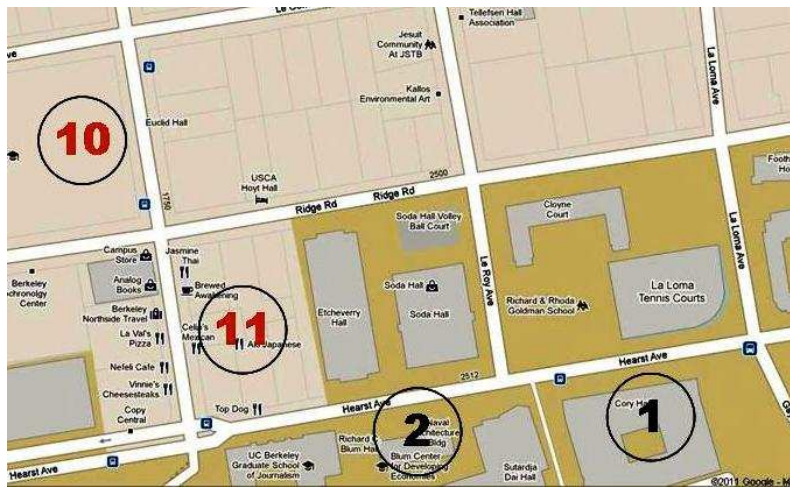


FIGURE 5. Land Use on Hearst and Euclid Avenues

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1 **Integration**

2 The results of the Space Syntax analysis are summarized in **TABLE 2** and **FIGURE 6**. The rows
 3 of the table are color coded to the same color of the lines in **FIGURE 6**. It shows that all the
 4 streets which are horizontal to campus are well integrated. Note that the size of the study area
 5 limits the number of links (intersections) between nodes (streets) to 3 at most. The calculate
 6 *integration* parameter is therefore automatically of radius 3.
 7

8 **TABLE 2. Space Syntax Parameters for the North Periphery of UC Berkeley**

Street	Total Depth	Mean Depth	Relative Asymmetry	Int[3]
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

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11 **FIGURE 6. Integration (Int[3]) for the North Periphery of UC Berkeley**

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14 **FIGURE 7** shows the relationship between integration and pedestrian volumes. Each
 15 point represents a single observation. There are roughly three levels of *Int[3]* while pedestrian
 16 traffic varies much more. **FIGURE 7** does not demonstrate any pattern that defines a relationship
 17 between *Int[3]* and pedestrian volumes. This result is not surprising and compares to those found
 18 in the literature (8). This strengthens the notion that predicating pedestrian activity based on
 19 *integration* is limited for certain locations.

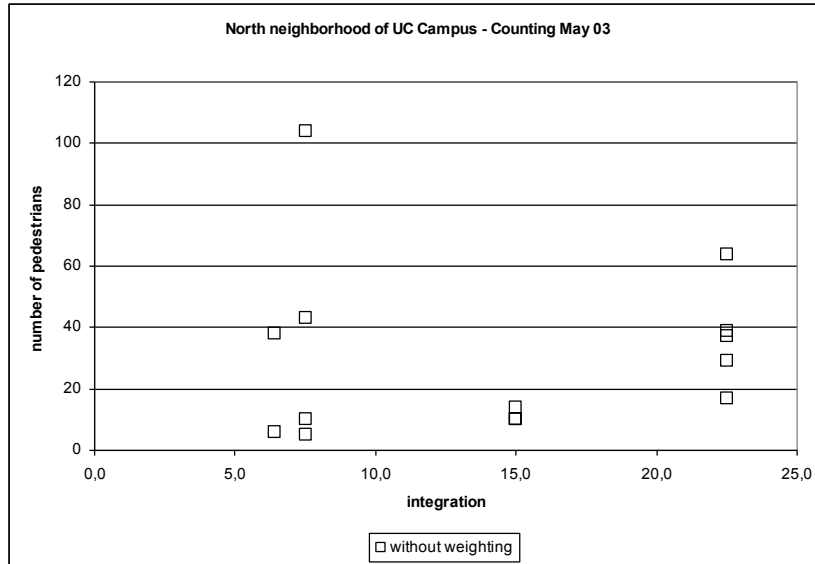


FIGURE 7. Relationship Between $Int[3]$ and Pedestrian Volumes

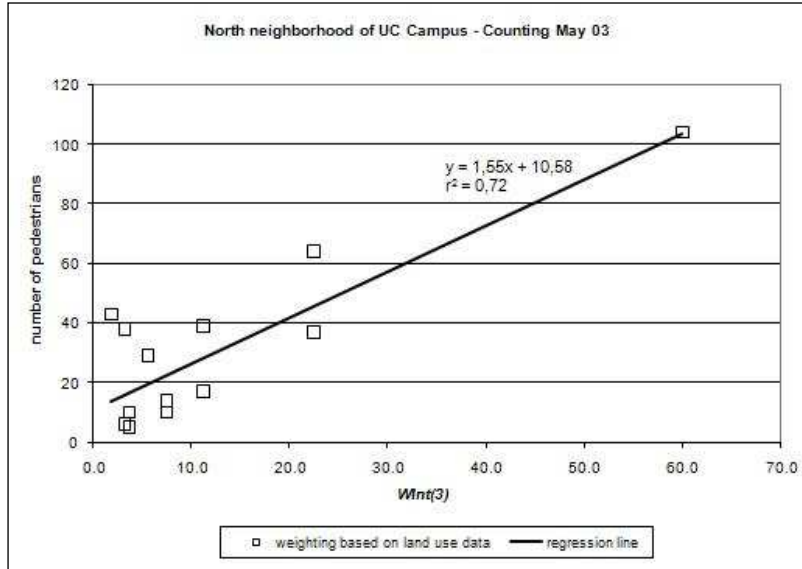
Weighted Integration

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

TABLE 3. Land-Use Related Weights

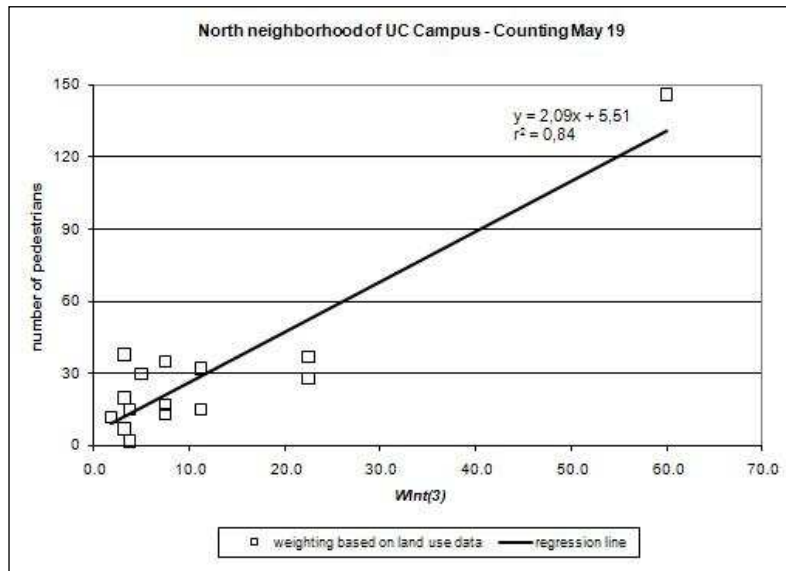
Gate	Street	Population	λ_1	Stores	λ_2	Transit	λ_3	λ_4	λ_5
		#/sq mile	habitation	#	activities	#stops/day	Transit	sidewalk	active
1	Hearst	12,616	0.5	0	1	262	2	1	0.5
2	Hearst	5,568	1	0	1	89	2	1	0.5
3	Hearst	7,535	1	3	1	173	2	0.5	0.5
4	Hearst	10,143	0.5	0	1	0	1	0.5	1
5	Hearst	3,940	1	0	1	343	2	1	0.5
6	Arch	16,743	0.5	0	1	0	1	1	1
7	Le Conte	19,885	0.5	0	1	0	1	1	1
8	Scenic	10,638	0.5	0	1	0	1	1	1
9	Virginia	19,518	0.5	0	1	0	1	1	1
10	Virginia	10,281	0.5	0	1	0	1	1	1
11	Le Conte	36,985	0.5	0	1	0	1	1	1
12	Euclid	8,037	1	22	2	30	2	1	2
13	Ridge	25,243	0.5	1	1	0	1	1	1
14	Le Roy	13,470	0.5	0	1	0	1	1	0.5
15	La Loma	14,135	0.5	0	1	0	1	1	1

The relationship between $WInt[3]$, taking into account the influence of land use, and the pedestrian volumes is shown in FIGURE 8. The regression line results in a high correlation coefficient of 0.72. Improvement can be seen compared with the FIGURE 7 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.



1
2 **FIGURE 8. Relationship Between *WInt(3)* and Pedestrian Volume – 5/3/2011**

3
4 The weighting method was also applied to the data from the second counting day of May
5 9. **FIGURE 9** demonstrates a similar correlation and strengthens the validity of the proposed
6 approach.
7



8
9 **FIGURE 9 Relationship Between *WInt(3)* and Pedestrian Volume - 5/3/2011**

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11
12 **SUMMARY AND CONCLUSIONS**

13 Under some scenarios an average *integration* value is not sufficient to describe the movement of
14 pedestrians along a street. This paper describes a relationship between the integration of a street,
15 derived from morphology analysis of an urban space, the land-use features of a street-block, and
16 pedestrian volumes for a street-block. Using Space Syntax to determine the *integration* of urban
17 streets, block-level land-use characteristics were applied as weights to adjust the initial

1 *integration*. A simple weighting mechanism is proposed to modify the value of integration at the
2 block level. Applying the proposed method for a north periphery of UC Berkeley has produced
3 promising results significantly improved the correlation between *integration* and pedestrian
4 volumes. These promising preliminary results have shown that this approach is valid and feasible
5 and warrants further study. Future research should address the weaknesses of the proposed
6 method by identifying more rigorous weighting factors and eliminating subjective elements
7 related to judging the dominance of land use features. The application of the proposed method to
8 a wider urban space should also help refine the choice of land use features. Applying a simple
9 weighting mechanism on *integration* using block-level land-use data can significantly improve
10 the correlation with pedestrian volumes and provide valid estimates of pedestrian exposure for
11 urban environments.
12

13

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