Factors of Perceived Walkability: A Pilot Empirical Study

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Abstract. We present preliminary results of a pilot empirical study designed to examine factors associated with pedestrians' perception of walkability, i.e. the perception of the quality, comfort and pleasantness of streets, and their conductivity to walk. Through a contingent field survey we collected 18 observable street attributes (independent variables), and a synthetic subjective perception of walkability (dependent variable), for the entire street network (408 street segments) of the city of Alghero in Italy. Regression analysis yields high goodness of fit (R-squared = 0.60 using all 18 variables), and points at 9 out of 18 as the most significant factors of perceived walkability ("useful sidewalk width"; "architectural, urban and environmental attractions"; "density of shops, bars, services, economic activities"; "vehicles-pedestrians separation"; "cyclability"; "opportunities to sit"; "shelters and shades"; "car roadway width"; "street lighting"; R-squared = 0.59). Among those, the first five factors in particular show as jointly most important as predictors of perceived walkability.

Keywords: Walkability · Regression analysis · Walkability perception · Urban design · Walkability audit

1 Introduction

This empirical study contributes to the ongoing multidisciplinary effort to pin down factors, their relative importance and their interactions, relevant for pedestrians' *perception* of walkability, that is to say, of the quality, comfort and pleasantness of streets, and their conductivity to walk.

In attempt to describe and explain people's propensity and decision to walk, their choices of pedestrian route and the qualitative perception thereof, scholars have examined a series of factors, related to individual characteristics (e.g. age, gender, income, etc.), mobility opportunities (e.g. availability of public transportation), trip types (purpose, frequency, available time, etc.), and features of the walking environment [1].

O. Gervasi et al. (Eds.): ICCSA 2016, Part IV, LNCS 9789, pp. 125–137, 2016.
DOI: 10.1007/978-3-319-42089-9_9

Our study focuses on this latter family of factors, related to the physical urban environment, and attempts to determine their correlation with the subjective, qualitative perception of the walking environment. Ultimately, the purpose is to provide useful indications both for modelling and evaluating urban walkability [2, 3], as well as for suggesting the most effective levers urban design and planning may be able pull to encourage walking behaviour by improving the pedestrian friendliness of cities [4].

Our study is based on a survey of the entire street network of the city of Alghero, a coastal town of approximately 40.000 inhabitants in the North-West Sardinia in Italy. Every street segment was audited for 18 *analytic* descriptive attributes, and was independently scored for its perceived overall walkability. This data allowed us to perform a regression analysis and to estimate the relationship between the analytic attributes and the synthetic perception of walkability.

In the next section we provide a brief review of approaches, methods and findings of similar studies reported in literature. Following we present the experimental design and settings of the study, and discuss its main findings.

2 Background

The question we attempt to address in our study is how the physical features of urban space influence the (qualitative) perception of its walkability. Scholars have employed a range of experimental designs, sets of dependent and independent variables, survey methods, and analytical tools to tackle this issue.

As dependent variables, one can find measurements of degree of satisfaction with urban environment [5, 6], the perception of its quality [7, 8], the perceived pedestrian-centred *Level of Service* (LOS) of street segments [9] and of street crossings [10, 11], the willingness to pay for improvements [12], the easiness of crossing [13], pedestrian accessibility [14], perceived safety and comfort [15], children safety and its perception by the parents [16, 17], and the relationship between children's and parents' choices of routes [18]. When attempting to acquire "objective" measures and observed behaviours, rather than declared qualitative perceptions and evaluative judgements, scholars have (with variable success) employed data on physical activity (and inactivity) [19, 20], use of public transportation [21], fraction of trips by foot [22], route choices [23], their feasibility [4] and their relation to personal traits [24].

Among independent variables, assumed as "predictors" of walkability, in literature we encounter three types of variables, along objective-subjective axis: (1) physical, functional and urban design features of space; (2) practices of use of space (frequencies, densities, flows, rates of use, etc.); and finally (3) individual perceptions or reactions to space [e.g. 25].

The first type of variables cover physical features (such as walkway width, number of car lanes, presence of green areas, landmarks and other "attractions", as well as the degree of maintenance). These measures may be strictly quantitative on cardinal scales (e.g. width in meters, car speed in km/h), or more qualitative usually evaluated on ordinal scale (e.g. degrees of maintenance).

The second type of variables describe phenomena related to how the space is being used, such as land uses, economic activities (bars, restaurants, shops, services, etc.), population densities, traffic flows, pedestrian flows, and so on.

Finally, the third type of variables are those more related to perception and reaction to space, such as sense of security, perceived urban quality, "sense of place", and so on.

As for the data collection and survey methods, scholars have been undertaking different routes. Direct, on-street survey methods can be classified [10] into:

- *observational method*, evaluating the LOS based on *in-situ* observation of pedestrian behaviour (pedestrian density, pedestrian flow rate, walking speed, etc.);
- *intercept survey,* interviewing pedestrians after they have traversed a crosswalk at intersection or a street segment and asking them to grade the crossing or the segment;
- *contingent field survey* (CFS), involves subjects walking along routes and instructed to grade each crosswalk or street segments immediately after they have traversed the intersection or the street;
- *controlled field valuation* (CFV) involves taking subjects to different intersections and letting surveyors observe and then grade the crosswalk without actually undertake the crossing; usually used for intersections, this method can also be adapted for the street segments;
- *laboratory/simulation studies* (LSS) involve subjects observing and evaluating a representation of the pedestrian environment; simulations may comprise various techniques to describe, represent and visualize the walking environment, from 3D renderings [e.g. 18], to photographs and photomontages [e.g. 12], to video clips [e.g. 6].

Among those mentioned, there are a few studies drawing methodological resemblances with ours.

Koh and Wong [23] conducted a survey to examine the influence of "infrastructural compatibility factors" on pedestrians' and cyclists' choices of commuting route. They combined interviews for stated preferences with walkability and bikeability audits, and compared the commuters' chosen routes with shortest available routes based on 11 infrastructural compatibility factors (for pedestrians: weather protection, distance, comfort, security, traffic accident risk, crowdedness, detour, number of road crossings/delay, stairs/slope, directional signs, good scenery and shops along route). For pedestrians, the study revealed a preference for routes that are comfortable, with shops and good scenery and preferably with the presence of other people (crowdedness).

Lamíquiz and López-Domínguez [22] use bivariate correlation and multivariate regression modelling to examine the association between features of the built environment (independent variables) and the proportion of pedestrians on all trips (dependent variable) in different parts of a city. The independent variables were organized in three groups: (1) street network (line length, segment length, etc.) and its configurational accessibility (connectivity, integration, etc.); (2) land use (including density and mix; and (3) non-built-environment variables (socio-economic characteristics, such as age and car ownership). Bivariate correlation showed a relatively high level of relation between pedestrian trips and about ten variables: their multivariate regression model yielded R-squared (adjusted) of 70.63 % using variables: mean line length, mean line density, percentage of culs-de-sac, “radius 5 integration”, intelligibility, “resid. + jobs + stud./Ha”, retail food units/Ha, retail units/Ha, jobs/residents, retail units/residents, retail food units/Res., distance to city center, percentage of residents > 65, and percentage of residents between 45–65 years.

In a study carried out by Evers *et al*. [16], parents volunteered to audit streets and intersections leading to seven elementary schools in a suburban school district. The parents were asked to report their agreement with the statement “I would feel comfortable letting an unsupervised 8-year-old child travel along/across this street/intersection”, on a 5-point Likert scale centered on neutral. Logistic regression models were created for street segments and intersections with the variables: traffic lines, turning lane, paved/planted median strip, trees presence, cul-de-sac end, likely place to walk, wheelchair accessibility, walking path wide, tripping hazards, obstructions, driveway hazard for the street segments and traffic control, size of intersection, “bumped-out” corner, curb cuts lack, crossing medians and crossing marked for the interactions. The final model predicting perceived lack of safety for street segments encompassed five predictors and performed well (R-squared = 0.632). Significant association were found with variables: street trees presence, most likely place to walk, traversable by wheelchair, free of tripping hazards, path obstructed intersection and size of intersecting roads.

Ling *et al*. [10] estimated the perceived pedestrian level of service (LOS), using correlation analysis and stepwise regression analysis. In this study, the LOS reflected pedestrians’ perception of crossing in safety and comfort. A *contingent field survey* was used to ask pedestrians to score crosswalks from 1 to 5. The relevant variables estimated by the stepwise regression (R-squared = 0.65) were found to be: entering right-turning motorized vehicles, leaving left-turning non-motorized vehicles, pedestrians volume at the beginning of green time, mixed cyclists volume, pedestrian delay (s), presence of refuge island, presence of two-step crossing.

Muraleetharan *et al*. [13] attempted to identify factors affecting pedestrian LOS at intersections. Factors examined were space at corner, visible cross markings, separate bicycle path, pathfinder tiles, curb ramps, number of lanes, refuge islands, turning vehicles, delay and pedestrian-bicycle interaction. A stepwise multivariable regression analysis was used to model the pedestrian LOS. The study revealed that the factor “turning vehicle” has greater influence on pedestrian LOS than any other. When the number of turning vehicles increases, the result shows a corresponding decrease in the perceived safety to the pedestrian. Furthermore, the factors “delays at signals” and “pedestrian-bicycle interaction” were also found to be significant factors in determining pedestrian LOS at intersections.

Jensen [6] attempted to determine the key variables influencing pedestrian satisfaction (stated preferences). The final regression model of LOS yielded the R-squared value of 0.55 for walkability, using as dependent variables: motor vehicles flow rate, average speed of motor vehicles, type of pedestrian facility (sidewalk - no sidewalk), type of bicycle facility (one-way bicycle track - bicycle lane - drive lane) and type of land use/buildings (shopping - residential - mixed use).

3 Experimental Design

Building on aforementioned studies, we conducted a *contingent field survey* (CFS) of the entire street network of the city of Alghero (Italy). The purpose of the survey was to collect two separate measures for each street segment of the city: (1) an *analytic* description of the street segment, through 18 observable street attributes; and (2) a *synthetic,* subjective perception of its quality of walkability.

The streets were divided into 408 homogeneous street segments, and the city was subdivides into 10 sectors (see Fig. 1). The survey was carried out in January 2016 by 24 graduate students split into 12 pairs, each pair assigned (1) to undertake a walkability audit of one urban sector (collecting 18 attributes for each street segment), and (2) to provide their subjective *synthetic* evaluation of the street segments in another sector. The two sectors assigned to each pair were different not to have their previous analytic knowledge influence their synthetic evaluation of streets.

A total of 483 records were collected, and then reduced to 408, one for each street segment, by averaging the values of multiple records referring to the same segment.

Fig. 1. 10 city sectors (right), and homogeneous street segments (example for Sector 7).

The list of the 18 analytic attributes are reported in Table 1. While some attributes do use qualitative levels, we provided auditors with detailed definitions and exemplifications to limit their interpretative ambiguity. So for example, for the five levels of the attribute "X1 Useful sidewalk width", the levels and their interpretations we provided as instructions to the auditors were: "1. Wide: allows comfortable passage for at least 4 people without obstacles; 2. Comfortable: allows passage for 3 people, even if with few minor nuisances; 3. Minimal: allows passage for 2 people, with obstacles that occasionally force to divert; 4. Inadequate: allows passage for only one person, with numerous obstacles along the route and detours; 5. Missing: no sidewalk, or impossible to use".

As for the *synthetic* subjective perception of the quality of walk, the auditors were asked to express their overall evaluative judgment about street segments by answering to the following question: "Express a *synthetic* evaluation of your perception of the

Table 1. List of street segment attributes.

Attributes (variables)	Scale levels
X1 Useful sidewalk width	1 Wide, 2 Comfortable, 3 Minimal, 4 Inadequate, 5 Missing
X2 Objects of architectural, urban and environmental attractions	1 Many, 2 Some, 3 Absent, 4 Some disturbing, 5 Many disturbing
X3 Density of shops, bars, services, economic activities	1 Plenty, 2 Some, 3 Few, 4 Absent
X4 Opportunity to sit (benches, etc.)	1 Extended, 2 Sparse, 3 Absent
X5 Shelters and shades	1 Strong, 2 Weak, 3 Absent
X6 Car traffic direction	1 Pedestrian street, 2 One way, 3 Two way
X7 Car roadway width	1 Pedestrian street, 2 One lane, 3 Two lanes, 4 Three lanes, 5 Four (or more) lanes
X8 Speed limit	1 Pedestrian street, 2 ≤20 km/h, 3 30 km/h, 4 50 km/h, 5 ≥70 km/h.
X9 Bicycle track (cyclability)	1 Off-road exclusive lane, 2 On-road exclusive lane, 3 On-road shared with vehicles, 4 Not permitted
X10 Degree of integration with surrounding space	1 Integrated, 2 Filtered, 3 Separated
X11 Vehicles-pedestrians separation	1 Pedestrian street, 2 Intense, 3 Weak, 4 Absent
X12 Street lighting	1 Excellent, 2 Good, 3 Inadequate, 4 Absent
X13 Sidewalk degree of maintenance	1 Excellent, 2 Good, 3 Mediocre, 4 Uneven, 5 Absent
X14 Street-level parking	1 Pedestrian street, 2 Allowed, 3 Not Allowed, 4 Illegal
X15 Physical car-speed reducers (hump, raised crossings, traffic islands, mini roundabouts)	1 Pedestrian street, 2 Many, 3 Some, 4 Few, 5 Absent
X16 Non-physical car speed reducers (traffic lights density, *enclosure*)	1 Pedestrian street, 2 High, 3 Medium, 4 Low, 5 Absent
X17 Crossings density (crossing opportunity)	1 Pedestrian street, 2 High, 3 Low, 4 Absent
X18 Road type	1 Pedestrian street, 2 Car street

quality and walkability of the street, from your point of view as pedestrian. The evaluation must be expressed on a qualitative scale from 1 ("insufficient") to 5 ("excellent"), taking into account the physical features of the pedestrian walkway, the overall qualitative characteristics of the urban space, and in general how you perceive the street to be safe, comfortable, pleasant, attractive and usable.

In order to express your evaluation, you *must not* take into account the distance from the city centre, nor the temporary sources of disturbance (such as public works, construction in progress, etc.)".

Following are the meanings of each evaluation level:

5. Excellent: maximum pedestrian comfort; the street is very pleasant to walk, with particularly attractive and valuable surrounding urban space or landscape where it is interesting to walk, sit and hangout.
4. Very good: the street is comfortable to walk, the pedestrian transit is pleasant and free of obstacles.
3. Good: the street can be walked, the pedestrian transit is without obstacles, but the surrounding urban space or landscape is not attractive.
2. Sufficient: the street is difficult to walk, there are obstacles to the pedestrian transit or the quality of the urban space and landscape is low, unpleasant or very disturbing.
1. Insufficient: the street is impossible to walk or feels very unsafe, the quality of the surrounding space or landscape is very disturbing.

4 Results

After uniformly re-scaling all the evaluations and grades on a scale from 0 to 1, we ran several multivariate linear regressions to explore models of correlation between the synthetic evaluation of walkability (dependent variable) and the street attributes (independent variables).

Table 2. Multivariate linear regression models

	Model A (R-squared = 0.60)			Model B (R-squared = 0.59)			Model C (R-squared = 0.56)		
	Est.	St. err.	p-val.	Est.	St. err.	p-val.	Est.	St. err.	p-val.
(Incpt.)	−0.209	0.049	3.e-05***	−0.210	0.046	8.e-06***	−0.049	0.032	0.126
X1	0.150	0.054	0.006**	0.202	0.048	3.e-05***	0.277	0.046	3.E-09***
X2	0.229	0.059	1.e-04***	0.236	0.056	3.e-05***	0.287	0.056	4.E-07***
X3	0.085	0.033	0.011*	0.101	0.032	0.002**	0.130	0.032	6.E-05***
X4	0.096	0.047	0.042*	0.107	0.046	0.020*			
X5	0.066	0.037	0.077	0.067	0.034	0.048*			
X6	−0.028	0.048	0.555						
X7	0.162	0.081	0.046*	0.119	0.067	0.077			
X8	0.116	0.092	0.209						
X9	0.169	0.067	0.012*	0.136	0.061	0.026*	0.197	0.0572	6.E-04***
X10	0.001	0.034	0.968						
X11	0.141	0.069	0.042*	0.129	0.055	0.019*	0.174	0.048	4.E-04***
X12	0.169	0.055	0.002**	0.212	0.050	3.e-05***			
X13	0.052	0.057	0.364						
X14	0.097	0.059	0.102						
X15	−0.048	0.071	0.498						
X16	−0.059	0.042	0.159						
X17	0.075	0.049	0.131						
X18	−0.094	0.066	0.160						

The first model, using all the available independent variables, yields R-squared = 0.60 (see Model A in Table 2). A subsequent model, using the 9 most significant variables from model A (and excluding "Street level parking" for low variability in the data) yields R-squared = 0.59 (see Model B in Table 2). These results point at the following nine variables as jointly most strongly associated with the overall synthetic perception of walkability: "Useful sidewalk width" (X1), "Objects of architectural, urban and environmental attractions" (X2), "Density of shops, bars, services, economic activities" (X3), "Opportunity to sit" (X4), "Shelters and shades" (X5), "Car roadway width" (X7), "Bicycle track (cyclability)" (X9), "Vehicles-pedestrians separation" (X11), and "Street lighting" (X12).

A graphical representation of two-way contingency tables between each of the nine variables and the dependent variable are shown in Fig. 2.

For a comparison of relative importance of independent variables, we ran separate monovariate linear regressions for those nine variables. From these results, reported in Table 3, we further note that the strongest individual effect may be observed on the variables X1, X2, X3, X9 and X11, each *individually* yielding R-squared > 0.20. A multivariate linear regression model using only those five variables yields R-squared = 0.56 (See Model C in Table 2.)

Using the model with nine variables for prediction (Model B), in Fig. 3 we compare the actual and the predicted values of synthetic evaluation of walkability.

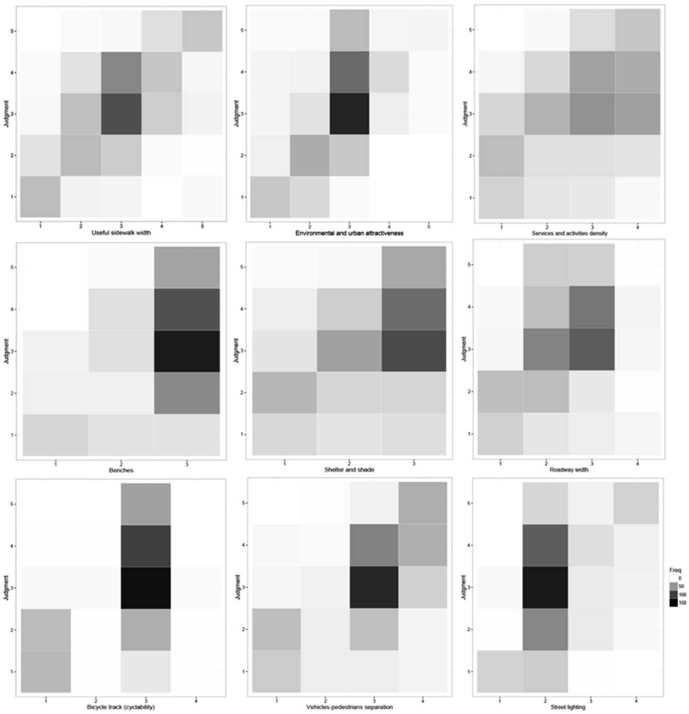


Fig. 2. Tile plot of judgments and street characteristics distribution of frequency.

Table 3. Monovariate linear regressions for the most significant independent variables

	X1	X2	X3	X4	X5	X7	X9	X11	X12
Coef. est.	0.6474	0.7637	0.3861	0.4598	0.3535	0.5540	0.6797	0.5804	0.5845
Std. error	0.0399	0.0559	0.0374	0.0520	0.0399	0.0676	0.0489	0.0379	0.0592
p-value	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16	3.4e-15	<2e-16	<2e-16	<2e-16
(Intercept)	0.2381	0.2017	0.3500	0.1979	0.3323	0.3509	0.1626	0.1939	0.2919
(Std. error)	0.0249	0.0317	0.0276	0.0483	0.0336	0.0340	0.0339	0.0290	0.0343
(p-value)	<2e-16	5.3e-10	<2e-16	5.1e-05	<2e-16	<2e-16	2.3e-06	7.3e-11	3.5e-16
R-squared	0.3931	0.3152	0.2082	0.1617	0.1620	0.1418	0.3220	0.3659	0.1935

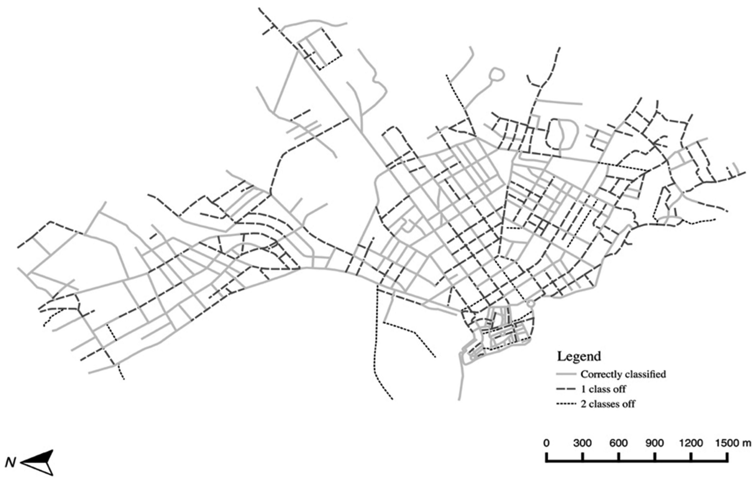
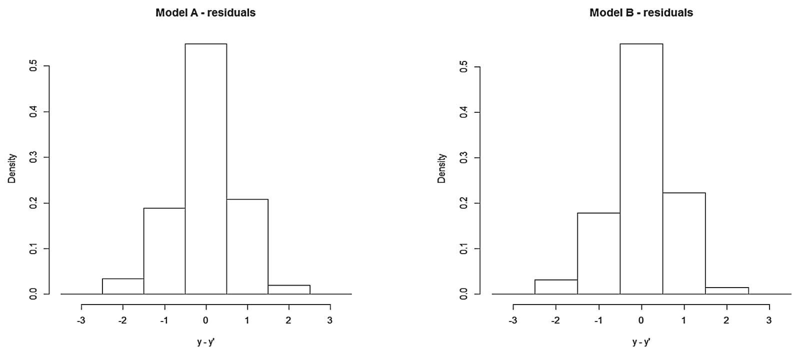
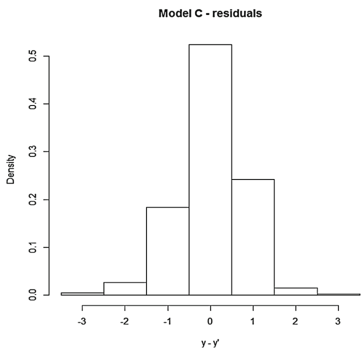


Fig. 3. Precision of street walkability predictions, using model B.





	Model A	Model B	Model C
Residuals			
Min.	-2.26	-2.41	-2.96
1st quartile	-0.44	-0.42	-0.49
Median	-0.03	-0.07	-0.10
3rd quartile	0.48	0.50	0.56
Max.	1.87	2.06	2.40
Classification			
Correct	54.90%	55.15%	52.45%
1 class off	39.71%	40.20%	42.66%
2 classes off	5.39%	4.65%	4.17%
3 classes off	0.00%	0.00%	0.74%

Fig. 4. Residuals for regression models

The distribution of residuals of this model are shown and reported in Fig. 4. From the summary data in the figure, one can note that the Model B predicts approximately 55 % of street segments in the correct class, and classifies over 95 % of street segments correctly or at most one class off from the actual synthetic evaluation assigned by the auditors.

5 Conclusion

The purpose of our study was to determine which urban features and design characteristics of the streets are most strongly correlated with a qualitative synthetic perception of the quality and walkability of streets. With respect to other similar studies, we have undertaken walkability audits to collect comparatively more detailed descriptions of the streets, both in terms of the number of descriptive attributes and in terms of modalities for some of the attributes. Furthermore, we used both qualitative and quantitative descriptors in a way to reduce equivocation and misunderstandings of the meaning of their respective scales of measurement.

In our *contingent field survey*, we were able to estimate the importance of street attributes in relation to the declared *synthetic* evaluation, and thus to avoid possible errors of direct declared valuation of relative importance of attributes by the interviewees. As noted by Guo *et al.* [4] "contingent rating based on stated preference may overestimate the importance of more tangible attributes, such as distance and safety, because pedestrians were often unable to articulate intangible amenities, such as streetscapes and façade designs". Judgments and walkability audits were also collected *in-situ* to capture as much as possible the real perceptions of the space, which could get lost in standard survey methods.

The results of regression analysis in particular show the following nine attributes to be highly significant and jointly yield a relatively high R-squared of 0.59: "Useful sidewalk width", "Objects of architectural, urban and environmental attractions", "Density of shops, bars, services, economic activities", "Vehicles-pedestrians separation", "Bicycle track (cyclability)", "Opportunity to sit", "Shelters and shades", "Car roadway width", and "Street lighting". These attribute are related to the pleasantness, comfort and safety, and are thus in accordance with Alfonzo's *et al*. [26] hierarchy of walking needs. Out of the nine attributes listed before, the first five in particular are revealed to be jointly most strongly associated with the perceived *synthetic* walkability (R-squared = 0.56).

As a prediction tool, the regression model using the above mentioned nine most significant attributes shows a fairly high precision of predictions (55 % streets classified correctly, 95 % classified correctly or at most ± 1 class off).

In future, we will intend to widen the sample and explore different statistical approaches, such as ordinal model, conjoint analysis, and part-worth function models. Also further investigation is needed to explore interactions between variables, which may me undertaken through choice modeling approaches.

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