Factors explaining perceptions of street quality and propensity to use urban streets

Zhuyin Lu; Jinjing Zhang; Paulo Anciaes and Peter Jones
Centre for Transport Studies, University College London

Presented at 19th Annual Transport Practitioners' Meeting, London 29-30 June 2022

Abstract

Many authorities are investing in street improvements to support their local high streets. However, there is still little knowledge on the attributes which influence people's perceptions of high street quality and that increase their propensity to use those streets. This paper investigates the relationships between objective conditions and subjective perceptions of street quality and performance, as well as the impacts of built-environment and demographic variables on pedestrian flows. Data from the TfL Healthy Streets survey was used as the primary source of subjective perceptions of street conditions; this interviewed 8,456 street users in 80 streets across London and collected their ratings on overall attractiveness, enjoyment and their perception of some environmental quality attributes of the street. The corresponding objective street features were mainly obtained using Google tools, with some other objective data coming from open access and government databases.

The associations between subjective and objective measures were analyzed using linear regression models. The results revealed both agreement and discrepancy between subjective perceptions and objective measures of the same street environments, and how these associations vary between different street user groups. The findings provide insights into people's perceptions of the built environment at the street level, and the types of street designs that can meet people's needs.

1. Introduction

Cities in most developed countries can currently be characterised as being a 'sustainable mobility city', as encouraged, for example, by the European Commission's promotion of SUMPs (Sustainable Urban Mobility Plans – see: https://www.eltis.org/sites/default/files/sump_guidelines_2019_interactive_document_1.pdf); however, many cities are now moving beyond this policy focus to one based on a 'city of places' (Jones et al., 2018). The key difference is that the 'city of places', while promoting sustainable mobility, is no longer just about moving people efficiently and healthily, but about creating a city that is a pleasant place to live in with an attractive physical environment and a focus on promoting livable communities. This is well demonstrated in London, where the Mayor's Transport Strategy promotes sustainable mobility and livability. In particular, the 'Healthy Streets' approach is designed to encourage active mode usage, improve road safety, air quality and the physical environment, and reduce car dependency and social exclusion through a well-designed street environment (Healthy Streets Surveys, n.d.).

The growing effort in developing a “city of places” is in contrast with a previous focus on designing for the 'link' function of streets (Jones, Roberts and Morris, 2007); this neglected the users' experience and walkability of the street, and discouraged pedestrians spending time on the streets (Rahman, Shamsuddin, and Ghani, 2015).

Although personal experience is given a high priority under the Healthy Streets Approach, there is a lack of comprehensive understanding of the links between how people perceive aspects of streets and the corresponding objective measurements. Also, the influence of perceived attractiveness on the number of pedestrians using the street is largely unknown. To fill in these gaps, this study has compared the reported subjective perceptions of street quality with their corresponding objective factors, and examined the impacts of perceived street quality on the number of pedestrians using urban streets. It provides some suggestions on how street design might be improved, based on these findings.

2. Study methodology

2.1. The Healthy Streets survey

The Healthy Streets Survey is an attitudinal survey, sampling people walking and dwelling on a section of street about their subjective perception of various aspects of the street’s performance. In the core part of the survey, respondents were asked to score thirteen elements of the street, including how satisfactory, attractive, enjoyable they think the street is, and how they perceive a range of street features (see Table 1). Most responses use a Likert scale from 0 (‘Not at all’) to 10 (‘Extremely’ satisfied), except for the last two questions about the walking and cycling environments, which were rated from 1 (‘Strongly disagree’) to 5 (‘Strongly agree’) that the street was suitable for walking/cycling. In addition, the survey recorded pedestrian counts, weather conditions, as well as the demographic information and trip characteristics of interviewees.

Eighty streets in central, inner, and outer London are covered in this survey, and nearly 8,500 pedestrians over the age of 16 took part, between 2014 and 2017, averaging over 100 respondents per street. The location of the 80 streets is shown in Figure 1.

Figure 1 Healthy Streets survey locations (Source of base map: Digimap)

Table 1. Questions measuring perceptions of the street environment

Questions	Variable names
How attractive do you find this street?	Attractive
How clean do you think the air on this street is today?	Clean Air
How noisy are you finding this street today?	Noise
How enjoyable are you finding being on this street today?	Enjoyable
How easy do you think it is to cross this street?	Easy to cross
How easy would it be for you to find somewhere to stop, sit or rest if you needed to?	Stop sit or rest
How easy would it be for you to find shelter, for example if it was very sunny or raining?	Shelter
How safe from crime and anti-social behaviour do you feel on this street today?	Safe from crime
How intimidated do you feel by the traffic on this street?	Intimidated by traffic
How would you rate the trees, plants and green spaces on this street?	Green spaces
How would you rate the quality of the pavements on this street, thinking about the pavement width, pavement surface and pavement obstructions?	Pavement quality
To what extent do you agree with the statement that 'this street provides a good environment for people to walk in'?	Good to walk
To what extent do you agree with the statement that 'this street provides a good environment for people to cycle in'?	Good to cycle

2.2. Collecting objective data

Google Street View, providing video stills of streets (Griew et al., 2013), was the primary tool for capturing street features such as the width of pavements, the presence of trees, benches, lighting, and crossing, supplemented in some cases by satellite views from Google Earth. It has been used successfully in several previous studies as a method for streetscape audits (Yin and Wang, 2016).

Digimap was used to measure street widths and corner radii, while other objective data (e.g. land use, population and Public Transport Accessibility Levels (PTAL) scores) were collected from a range of official databases online.

Appendix A sets out the categories of objective variables, their definitions, and data sources. There are, in total, 50 objective measures of street quality and performance, in terms of traffic, infrastructure for pedestrians, cyclists, and public transport, greenery, crime and collision, air pollution, land use, weather and demography.

2.3. Data analysis

We used multivariate linear regression models to describe the relationships between two sets of variables:

a) thirteen pairings of perceived and objective indicators of street quality, based on over 8,000 observations (averaged per street); and

b) overall perceptions of street quality and pedestrian flows, comprising 80 sets of observations, which can be sub-categorised by population groups. Here a range of other factors that might affect pedestrian flow are also considered, including percentage of non-rainy days, population density, presence of a railway station and PTAL score, diversity, and different categories of land use area.

Highly correlated independent variables are omitted from the models, which were adjusted and rerun to obtain the best model fit.

3. Study findings

3.1. Relationships between perceptions and objective indicators of street quality

The main findings are summarized in Table 2, presenting the association between 13 sets of subjective street ratings (the columns in the table) and 43 objective indicators of street quality and performance (in the rows). Cells showing relationships between variables that are significant at the **0.05 level are shaded in green** and those significant at the **0.10 level are shaded in yellow**. Overall goodness-of-fit measures (adjusted r^2) are provided along the bottom row and range between a low of 0.131 (shelter) and a high of 0.440 (good to cycle).

Findings are summarised below and the detailed models (one for each column) are provided in **Appendix B**.

Table 2. Relationships between subjective perceptions and objective street measurements

OBJECTIVE FACTORS ↓			SUBJECTIVE FACTORS [Higher score = conditions perceived to be better]												
			Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13
			Attractive	Clean air	Noise	Enjoyable	Easy to cross	Stop sit or rest	Shelter	Safe from crime	Intimidated by traffic	Green spaces	Pavement quality	Good to walk	Good to cycle
Vehicle related elements	1	Motorised traffic volume					–			–	–				–
	2	Percentage of large vehicles					+				+				
	3	Speed of motorised traffic													
	4	Noise			–										
	5	Density of parking and loading bays					+				+				
	6	Maximum width of carriageway	–	–		–									
	7	Minimum width of carriageway													
	8	Density of sideroads	+			+									
	9	Maximum geometry of curve of side road									–				
	10	Minimum geometry of curve to side road													
Pedestrian related facilities	11	Density of crossings													
	12	Type of crossing													
	13	Presence of street with pedestrian refuge													
	14	Maximum width of pavement													
	15	Minimum width of pavement											+		
	16	Quality of pavement	+			+	+			+	+		+	+	
	17	Pedestrian volume			+									+	
	18	Density of resting points						+							
	19	Density of shelters							+						

OBJECTIVE FACTORS ↓			SUBJECTIVE FACTORS												
			Attractive	Clean air	Noise	Enjoyable	Easy to cross	Stop sit or rest	Shelter	Safe from crime	Intimidated by traffic	Green spaces	Pavement quality	Good to walk	Good to cycle
Cyclist related facilities	20	Density of cycle parking	–			–									
	21	Cycle volume													+
	22	Presence of other cycle facilities													
	23	Presence of cycle lanes													+
Bus related facilities	24	Density of bus stops												–	
	25	Bus lane operation													
	26	Presence of shelter at bus stop						+	+						
Greenery	27	Density of trees										+			
	28	Density of other planting													
	29	Density of parks										+			
Safety and crimes	30	Density of lighting columns								–					
	31	Density of street crimes													
	32	Density of total collisions					–				–				
Other objective elements	33	NO2													
	34	PM 2.5													
	35	PM 10		+											
	36	Percentage of land uses that are residential													
	37	Percentage retail		–											
	38	Percentage office	+		+	+		+							
	39	Percentage community													
	40	Percentage recreational													
	41	Percentage transport-related			–										
	42	Percentage commercial													
	43	Percentage other													
MODELS	Adjusted R^2		**0.308**	**0.271**	**0.235**	**0.320**	**0.358**	**0.154**	**0.131**	**0.280**	**0.427**	**0.273**	**0.368**	**0.414**	**0.440**

Attractive

Model 1 explains 30.8% of the variation in the attractiveness. Among the five significant design variables, pavement quality has the largest positive influence on the perceived attractiveness of the street, while the density of cycle parking shows the largest negative effect; this may be because the parking of bicycles will narrow the sidewalk and affect the perception of pedestrians. The percentage of office areas has a positive effect on the level of attractiveness, which is consistent with the conclusion in earlier studies (Borst et al., 2008). The density of side roads is found to be positively related to perceived attractiveness, which suggests that accessibility to the surrounding street network may increase attractiveness. Conversely, a wider carriageway reduces the overall attractiveness.

Clean air

Model 2 shows the relationship between the street features and the ratings on air quality. There is a high correlation among NOx, PM2.5, and PM10; given that, we chose to include only PM10 because particulate matter (PM) has caused a series of adverse health problems for roadside street users (Lin et al., 2016; Chen et al., 2021) and is more likely to be perceived due to its larger diameter. Other explanatory variables, such as the percentage of large vehicles and the density of various greeneries are excluded due to their high correlation with PM10. The model has an Adjusted R^2 of 27.1%.

The maximum width of carriageway is negatively correlated with the perceived quality of the air (significant at 0.the 05 level), as is a higher percentage of retail area (at a 0.1 level).

Surprisingly, the coefficient for PM10 is positive, indicating that a street with a higher PM10 concentration has a higher air quality satisfaction score. This suggests that it is hard to identify relationships between perceived and actual levels of air pollutants (Brody et al., 2004), as the individual ratings can be affected by different standards of overall comfort and other environmental parameters (Nikolopoulou et al., 2011).

Noise

Model 3 shows the relationship between street environment and people's perception of noise (10 means not at all noisy and 0 means extremely noisy), for which the Adjusted R^2 is 23.5%. The perceived noise score is closely related to the estimated noise level on the street (0.05 level), while a higher pedestrian volume is positively associated with the perceived quietness of the street. A higher percentage of offices is also associated with an increased level of perceived quietness, while the percentage of land use allocated to transport uses shows a negative effect on the ratings for Noise.

Enjoyable

Model 4 explains 32.0% of the variation in the perception of the streets as enjoyable. All the explanatory variables significant in Model 1 are also significant Model 4; namely, quality of pavement, density of sideroads and % of office land use (positive) and maximum width of carriageway and density of cycle parking (negative).

This is to be expected, as the variables Attractive and Enjoyable have a very high correlation (Pearson correlation coefficient of 0.94),

Easy to cross

Model 5 illustrates the relationship between several street elements and perception of the ease of crossing the street, and explains 35.8% of the variation in the perception scores. The logarithm form of motorised traffic volume and the density of total traffic collisions both have significant and negative effects, while the pavement quality is positively associated with the ease of crossing the street.

However, two findings are unexpected.

First, the percentage of large vehicles shows positive influence on the perceived easiness of crossing the street. Here there might be two possible explanations: a) Most people driving large vehicles (e.g. buses and trucks) are professional and experienced drivers, so they are more likely to pay more attention to pedestrians and give way to them; or b) People more readily notice large vehicles due to their larger visual envelope and lower speed compared with cars.

Second, the density of parking or loading bays is positively related to ease of crossing, which might suggest that the vehicles parking along the streets reduce the effective width of the streets, making them easier the cross.

Stop sit or rest

Model 6 presents the relationship between the objective features and the subjective scores on the 'easiness to find somewhere to stop, sit or rest'; the Adjusted R^2 for is 15.4% and three factors are positively correlated: the density of resting places and the percentage of office land use (at 0.05 level of significance), while the presence of a shelter at a bus stop is also significant, at 0.1 level.

Shelter

Model 7 shows the results of the 'easiness to find shelter on the street', for which the Adjusted R^2 is 13.1%. Here only the density of shelters and the presence of shelters at the bus stops are significant.

Safe from crime

Model 8 presents the relationship between objective elements and whether people feel safe from crime and anti-social behaviour on the street; here the Adjusted R^2 is 28.0 %. The motorised traffic volume has a significant negative effect on the perceived safety of the street; as does, surprisingly, the density of lighting columns, which generally shows a positive and significant influence on enhancing safety in previous studies (Painter, 1996; Foster et al., 2013; Xu et al., 2018. This might indicate that street designers need to consider not only the number of lighting columns, but also which parts of the street should be lit for people to feel safe (Haans and Kort, 2012). Pavement quality is significant and positive with a relatively high coefficient, which is consistent with the Broken Windows Theory (Wilson & Kelling, 1982). It is worth noting that the number of reported street crimes did not show a significant association with the perception scores.

Intimidated by traffic

Model 9 illustrates the relationship between street features and the level of intimidation caused by traffic (where 10 means feel not at all intimidated and 0 means feel extremely intimidated). It explains 42.7% of the variation. in the perception of intimidation. Here many variables were significant, but not always in the expected direction. A higher percentage of large vehicles was associated with people reporting being less intimidated by traffic. A greater density of parking and loading areas was also associated with reduced intimidation, which could result from kerbside vehicles providing a safety buffer between pedestrians and passing traffic. Better quality pavements were also positively associated with feeling less intimidated Conversely, the motorised traffic volume, the density of reported traffic accidents, and the maximum radii at sideroad junctions all had negative effects on the ratings – as would be expected. Interestingly, the speed of motorised traffic was not significant.

Green spaces

Model 10 shows the relationship between the objective measures of provision of trees, plants, and green spaces and their subjective ratings; the adjusted R^2 is 27.3%. The density of trees and of parks are both highly significant in this model, indicating that people recognize and value the presence of street greenery (Klemm et al., 2015). The coefficient of the density of parks are much higher than that of the density of trees, which shows that the existence of the park can affect people's subjective perception more.

Pavement quality

Model 11 estimates the relationship between street features and pavement quality. The adjusted R^2 is 36.8%, and two explanatory variables both have significant and positive effects: the minimum width of pavement (0.10) and the pavement quality

(0.05). The latter has a coefficient of 0.671, suggesting a very high and strong correlation between objective measures of pavement quality and user perceptions.

Good to walk

Model 12 explores the relationship between the objective variables and the ratings on whether people think the street was a good environment to walk in (1 is strongly disagree and 5 is strongly agree). The adjusted R^2 is 41.0% and three variables are significant: two are positively correlated with 'good to walk' (the quality of pavement and the logarithmic form of pedestrian flow), while the density of bus stops is negatively correlated. The negative coefficient of bus stop might indicate that people regard the existence of a bus stop as an obstacle to movement along the pavement, because it takes up a certain amount of space and queues at the bus stop might block the footway. The high coefficient for pedestrian volume indicates that people are prone to give higher ratings on the walkability of the streets where there are higher pedestrian volumes. It might also suggest that busy streets might be considered good to walk because of the presence of more human activity (Borst et al., 2008).

Good to cycle

Model 13 shows the relationship between the objective variables and the extent people agreed with the statement that the street was a good environment to cycle in (1 is strongly disagree and 5 is strongly agree). The Adjusted R^2 is highest in this case, at 44.0%, and the cycle related variables (cycle volume and the presence of marked cycle lanes) are both significant with a positive effect. While, as expected, motorised traffic volume has a significant and negative influence on people's ratings of the street in terms of 'good to cycle'.

3.2 Perceptions of street quality and pedestrian flows

We first estimate a general model between perceptions of street quality and pedestrian flows and then separate models by age group and gender.

Results are summarized in Table 3. Detailed results of each model are listed in **Appendix B.**

Table 3. Relationship between number of pedestrians and twelve factors

Independent Variables		Dependent Variables: Number of pedestrians on the street					
		Full sample	16-44	45-64	65+	Male	Female
Perceived variables	Attractiveness	+	+	+		+	+
	Ease of crossing the road	-	-	-			
Weather	Percentage of not raining days						
Demography	Average population density	+	+			+	
Accessibility	Whether it is a high PTAL area	+	+	+		+	+
	Presence of a railway station	+	+			+	
Land use	Shannon's Diversity Index (SHDI)						
	% Residential use area		-			-	
	% Office use area						
	% General and mixed retail area	+	+	+	+	+	+
	% Community use area						
	% Recreational use area	+	+			+	+

Basic model: full sample

7 of the 12 variables are significant in the basic model, 6 of which are positively correlated with observed pedestrian volumes.

Rated attractiveness, average population density within a 400m buffer of the street, the presence of a railway station, a high PTAL (public transport accessibility level) score, and the 5 of general retail area are all highly significant and positively related to pedestrian flow. The % recreational area is more weakly significantly related to pedestrian flow.

'Easy to cross' is the only attitudinal variable showing a significant negative correlation with observed pedestrian volumes. This might be explained by the busy streets, which meet persons' activity requirements have high traffic and pedestrian volumes at the same time, and so more limited crossing opportunities.

Age-segmented models

As the age of respondents increases, fewer variables are found to be significant: 8 of the 12 variables are significant between 16 and 44 years old; 4 of the 12 variables are significant at age 45 to 64, and only 1 variable is weakly significant among people who are over 65 years old.

The % area of general retail land is significant and positive in all models. The perceived attractiveness of the street, ease of crossing the street, and PTAL score are significant factors that affect footfalls of those from 16 to 64 years old. Only population density, presence of railway stations, the % area of recreational and residential lands seem to be related to the number of people between 16 and 44 years old.

Other factors, including the land-use diversity, office, and community area, are insignificant in all cases.

Gender

Regarding the gender difference among pedestrians, 7 of 12 factors are significantly correlated with the number of male pedestrians, while only 4 relate to the observed number of female pedestrians.

The street's PTAL score, % area of general retail and recreational land relate to both male and female pedestrian flows significantly and positively. The key design variable of interest, the perceived attractiveness of the street, is weakly significant for both males and females, but the size of the coefficient is less than that of PTAL and % retail area. The presence of railway stations and % area of residential spaces and population density seem to relate only to the number of male pedestrians.

Weather conditions, perceived ease of crossing, diversity, % office area, and % community lands are insignificant in both the gender and age segmented models.

4. Implications for future street design

Pavement quality was found to be a key factor in increasing the positive perceptions of street users. Except for the weather, pavement quality is the only objective element significantly influencing 7 subjective variables, and the coefficient of pavement quality in the regression models is often higher than that of other objective factors. This finding highlights the importance of maintaining the quality of footways, as through high quality provision and the long-term maintenance of pavements, it is possible to maintain people's overall positive perceptions of a street.

Although sustainable transport (especially buses and cycles) has a series of benefits and is encouraged in many cities (Transport for London, 2017), the existence of some public facilities may negatively affect the perception of pedestrians, as the model showed that the density of bus stops and cycle parking can have a significant and negative influence on people's ratings of streets in terms of the variables Attractive, Enjoyable and Good to walk. Therefore, it is necessary to carefully find a balance between the distribution of transport infrastructure and the needs of pedestrians.

The consistent significance of public transport accessibility (PTALs) as an explanator of pedestrian flows confirmed that reducing the distance to bus and railway stations and increasing the frequency of public transport services can encourage people to visit a street. The presence of railway stations is significant in the full model, among the 16-44 age group, and males, suggests that the presence of a railway station is more important for some groups than for others.

The positive and significant relationship between the % general retail area and footfall indicates that increasing the area of the existing retail offer or building new retail stores can attract pedestrians from all age groups and genders. The other land uses only encourage some groups of pedestrians to visit the street. Expanding the % recreational area only seems to attract people below 45 years old, while a higher % residential area is associated with fewer males and people aged between 16 and 44.

Population density is significant in increasing pedestrian flows in the full model, among people aged 16 to 44, and males. However, in other studies, the relationship between number of trips and population density has shown an inverse U-shape: more trips may be generated the higher the population density; but at a certain point, further increases in density have been found to result in a decreasing trend in walking for leisure (Lu, Xiao and Ye, 2017).

5. Conclusions

Street quality is appreciated by street users and influences pedestrian behaviour. Improving street quality, especially the attributes with the strongest associations with perceptions and behaviour, is vital to promote high street vitality, sustainable transport, and healthy cities. The relationship between perceptions and objective indicators of street quality, and between perceptions of street quality and pedestrian flows are examined in two separate sets of models, based on two sets of data for 80 high streets in London. The study provides suggestions on how to improve future street design.

The first set of regression models provided insights into people’s perceptions of the built environment at the street level. The variables Good to walk, Good to cycle and Intimidated by traffic are the subjective variables best explained by the objective measures, all with an Adjusted R^2 of greater than 0.4. Overall, pavement quality is the objective measure providing the most explanatory power, which shows a positive and significant effect on 7 subjective variables in total and has a high coefficient in most cases. Motorised traffic volume and the percentage of office area are also significant as they influence 4 subjective variables.

Conversely, several objective street features were not significantly associated with any of the attitudinal scores. These include the density and type of crossings, the speed of motorised traffic, and 16 other variables. In most cases, statistically significant associations demonstrate consistency between perceptions and objective indicators, such as people's perception of green spaces and the density of trees.

In the second set of regression models, built-environment variables were combined with perceived factors to assess the impacts on footfall among different age groups and genders. Pedestrian flows were significantly associated with the overall perceived attractiveness of the street, ease of crossing the road, public transport accessibility and % area of mixed retail land use. Factors including weather, land use diversity, % area of office and % community uses had no effect on pedestrian volumes in any of the examined groups. Population density, % area of residential and % area of recreational uses land are significant in a few cases. However, their significance and magnitude of associations differed by age and gender, and the tested factors are more sensitive for age groups than genders.

Overall, the numbers of pedestrians of different age groups and genders attracted to a street are affected differently by build-environment variables. This suggest that local authorities could increase footfall by selectively making improvements based on the characteristics of demographic structure in the local area. For example, planning for more recreational land uses in areas with higher proportions of younger people. Improving street attractiveness, transport accessibility, ease of crossing the road and a greater % of mixed retail land can be implemented in any of the areas to attract greater footfall, because they are significant in increasing pedestrian volumes for all groups.

References

Borst, H.C., Miedema, H.M.E., de Vries, S.I., Graham, J.M.A. and van Dongen, J.E.F. (2008). Relationships between street characteristics and perceived attractiveness for walking reported by elderly people. Journal of Environmental Psychology, 28(4), pp.353 ‐ 361.

Brody, S.D., Peck, B.M. and Highfield, W.E. (2004). Examining Localized Patterns of Air Quality Perception in Texas: A Spatial and Statistical Analysis. Risk Analysis, 24(6), pp.1561–1574.

Chen, X., Wang, X., Wu, X., Guo, J. and Zhou, Z. (2021). Influence of roadside vegetation barriers on air quality inside urban street canyons. Urban Forestry & Urban Greening, 63, p.127219.

Foster, S., Wood, L., Christian, H., Knuiman, M. and Giles-Corti, B. (2013). Planning safer suburbs: Do changes in the built environment influence residents' perceptions of crime risk? Social Science & Medicine, 97, pp.87–94.

Griew, P., Hillsdon, M., Foster, C., Coombes, E., Jones, A. and Wilkinson, P. (2013).

Developing and testing a street audit tool using Google Street View to measure environmental supportiveness for physical activity. International Journal of Behavioral Nutrition and Physical Activity, 10(1), p.103.

Haans, A. and de Kort, Y.A.W. (2012). Light distribution in dynamic street lighting: Two experimental studies on its effects on perceived safety, prospect, concealment, and escape. Journal of Environmental Psychology, 32(4), pp.342–352.

Healthy Streets Surveys. (n.d.). [online]. Available at: http://content.tfl.gov.uk/healthy-streets-surveys.pdf [Accessed 31 Aug. 2021].

Jones, P., Anciaes, P.R., Buckingham, C., Cavoli, C., Cohen, T., Cristea, L., Gerike, R., Halpern, C. and Pickup, L. (2018). *Urban mobility: preparing for the future, learning from the past - CREATE project summary and recommendations*. [online] discovery.ucl.ac.uk. Available at: https://discovery.ucl.ac.uk/id/eprint/10058850/ [Accessed 31 Aug. 2021].

Jones, P., Roberts, M. and Morris, L. (2007). *Rediscovering mixed-use streets: the contribution of local high streets to sustainable communities*. [online] *westminsterresearch.westminster.ac.uk*. Bristol: Policy Press in association with the Joseph Rowntree Foundation. Available at: https://westminsterresearch.westminster.ac.uk/item/91y5x/rediscovering-mixed-use-streets-the-contribution-of-local-high-streets-to-sustainable-communities [Accessed 6 Jun. 2021].

Klemm, W., Heusinkveld, B.G., Lenzholzer, S. and van Hove, B. (2015). Street greenery and its physical and psychological impact on thermal comfort. Landscape and Urban Planning, 138, pp.87–98.

Lin, M.-Y., Hagler, G., Baldauf, R., Isakov, V., Lin, H.-Y. and Khlystov, A. (2016). The effects of vegetation barriers on near-road ultrafine particle number and carbon monoxide concentrations. Science of The Total Environment, 553, pp.372–379.

Lu, Y., Xiao, Y. and Ye, Y. (2017). Urban density, diversity and design: Is more always better for walking? A study from Hong Kong. *Preventive Medicine*, 103, pp.S99–S103.

Office for National Statistics (2020). *Estimates of the population for the UK, England and Wales, Scotland and Northern Ireland - Office for National Statistics*. [online] Ons.gov.uk. Available at: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland.

Painter, K. (1996). The influence of street lighting improvements on crime, fear and pedestrian street use, after dark. Landscape and Urban Planning, 35(2-3), pp.193–201.

Rahman, N.A., Shamsuddin, S. and Ghani, I. (2015). What Makes People Use the Street?: Towards a Liveable Urban Environment in Kuala Lumpur City Centre. *Procedia - Social and Behavioral Sciences*, [online] 170, pp.624–632. Available at: https://core.ac.uk/download/pdf/82697473.pdf [Accessed 17 Sep. 2020].

Transport for London. (2017). Guide to the Healthy Streets Indicators. [Online] Available from: http://content.tfl.gov.uk/guide-to-the-healthy-streets-indicators.pdf [Accessed 16th January 2021]

Transport for London. (2017). Healthy Streets Check for Designers. [Online] Available from: http://content.tfl.gov.uk/healthy-streets-for-london.pdf [Accessed 17th January 2021]

Transport for London. (2017). Healthy Streets for London. [Online] Available from: https://tfl.gov.uk/cdn/static/cms/documents/healthy-streets-check-for-designers-2018.xlsx [Accessed 17th January 2021]

Transport for London. (2019). Streetscape Guidance. [Online] Available from: https://content.tfl.gov.uk/streetscape-guidance-.pdf [Accessed 1st July 2021]

Wilson, J., & Kelling, G. (1982). BROKEN WINDOWS: THE POLICE AND NEIGHBOURHOOD SAFETY. The Atlantic Monthly, 249, 0-0.

Xu, Y., Fu, C., Kennedy, E., Jiang, S. and Owusu-Agyemang, S. (2018). The impact of street lights on spatial-temporal patterns of crime in Detroit, Michigan. Cities, 79, pp.45–52.

Yin, L. and Wang, Z. (2016). Measuring visual enclosure for street walkability: Using machine learning algorithms and Google Street View imagery. Applied Geography, 76, pp.147–153.

Appendix A – Data sources of measured objective elements

Variables	Definitions	Source
Traffic (10 variables)		
Motorised traffic volume	Total volume of two-way motorised traffic (Vehicle per hour)	Healthy Streets Survey: HAM data (2014-2016)
The percentage of large vehicles	(Actual flow of heavy goods vehicle + Actual flow of large good vehicles) / Total motorised traffic volume	
Speed of motorised traffic	The average speed of motorised traffic volume (km per hour)	
Noise	Traffic noise based on peak hour motorised traffic volumes (dB)	Department for Environment Food & Rural Affairs: Noise Pollution in London (2015)
Density of parking and loading bays	The length of marked parking the loading bays / The length of street	Google Street view (2014-2016)
Maximum width of carriageway	The maximum width of carriageway (m)	
Minimum width of carriageway	The minimum width of carriageway (m)	
Density of sideroad	The number of sideroad / The length of street (number per 100m)	
Maximum geometry of curve of sideroad	The minimum area of the geometry of curve of sideroad (m2)	
Minimum geometry of curve of sideroad	The minimum area of the geometry of curve of sideroad (m2)	
Pedestrian (9 variables)		
Density of crossing	The number of crossings / The length of street (number per 100m)	Google Street View (2014-2016)
Type of crossing	The type of crossing (use dummy variables to represent signalised, unsignalised, and the mix of the presence of signalised and unsignalised crossings on the street)	
Presence of pedestrian refuge	The presence of pedestrian refuge/ pedestrian island/ median strip (use dummy variables to represent yes and no)	
Maximum width of pavement	The maximum width of walking space (m)	
Minimum width of	The minimum width of walking space	

pavement	(m)	
Quality of pavement	Refer to the Pavement Asset Management Guidance (Irish Pavement Asset Group, 2014) 4 Good; 3 Safe, but poor appearance; 2 Minor (functional) deterioration; 1 Major (structural) deterioration	
Pedestrian flow	Average pedestrian flow (ppl/min)	Healthy Street Survey (2014-2016)
Density of resting points	The number of resting points (benches and other informal seating) / The length of street (number per 100m)	Google Street View (2014-2016)
Density of shelter	The number of sheltered areas (including awning of shop, bus stop and telephone booth) / The length of street (number per 100m)	
Cyclist (4 variables)		
Density of cycle parking	The number of cycle parking facilities / The length of street (number per 100m)	Google Street View (2014-2016)
Presence of other cycle facilities	Apart from the provision cycle parking, the presence of additional cycle facilities (such as exclusive bike lane, bike box)	
Presence of cycle lane	The density of marked cycle lane along the street (use dummy variables to represent the cycle lane of both sides, one sides, and none)	
Cycle volume	Cycle flow (Cycle per min)	Healthy Street Survey (2014-2016)
Public transport (5 variables)		
Density of bus stop	The number of bus stop / The length of street (number per 100m)	Google Street View (2014-2016)
Bus lane operation	The presence of exclusive bus lane (use dummy variables to represent the bus lane of both sides, one sides, and none)	
Presence of shelter at bus stop	The presence of shelter at bus stop (use dummy variables to represent yes and no)	
PTAL_dummy	Dummy of Public Transport Accessibility Level (1: PTAL greater or equal to 6a, 0: PTAL below 6a)	Web-based Connectivity Assessment Toolkit (2011) Website: https://tfl.gov.uk/info-for/
Railway_dummy	Dummy of railway station (1: railway	

	station, 0: no railway station)	urban-planning-and-construction/planning-with-webcat/webcat
Greenery (3 variables)		
Density of trees	The number of street trees / The length of street (number per 100m)	Google Street View (2014-2016)
Density of other planting	The length of planting at footway-level (excluding trees) / (The length of street×2)	
Density of park	The length of park along the street / (The length of street×2)	
Crime and collision (3 variables)		
Density of lighting columns	The number of lighting columns on both sides / the length of street (number per 100 metres)	Google Street View (2014-2016)
Density of street crimes	The annual number of street crimes / The length of street (number per 100m)	POLICE UK: Crime Data (2015)
Density of total collision	The sum of the annual number of slight, serious and fatal collisions / The length of street (number per 100m)	Transport for London: Road Safety Data (2015)
Air pollution (3 variables)		
NO2	NO2 concentration (µg/m3)	Greater London Authority: London Atmospheric Emissions Inventory: Grid emissions summary (2016)
PM 2.5	PM 2.5 concentration (µg/m3)	
PM 10	PM 10 concentration (µg/m3)	
Land use (10 variables)		
Residential	Residential use area within a 100m buffer (hm^2)	Digimap Geomni
Retail	Retail use area within a 100m buffer (hm^2)	
Office	Office use area within a 100m buffer (hm^2)	
Community	Community use area within a 100m buffer (hm^2)	
Recreational	Recreational and leisure area within a 100m buffer (hm^2)	
Transport	Transport use area within a 100m buffer (hm^2)	
Commercial	Commercial use area within a 100m buffer (hm^2)	
Other	Other use area within a 100m buffer	

	(hm^2)	
Diversity	Shannon's Diversity Index (SHDI) within a 100m buffer	
Retail_mix	Combined of general retail use area and retail with office/residential above within a 100m buffer (hm2)	
Weather (2 variables)		
Perc_no_rain	Percentage of not rainy days during interview	Time and Date AS
Avg_daylight	Average daylight hours during interview (min)	
Demography (1 variable)		
Pop_den400	Average population density within a 400m buffer (ppl/m2)	Office for National Statistics

Appendix B – Detailed models

The basic principles of excluding the explanatory variables are:

- If some explanatory variables are highly correlated, the model gave priority to the variables having more direct relationship.
- If some explanatory variables are highly correlated, the model gave priority to the design variables (e.g. street width) over performance variables (e.g. pedestrian volumes).
- If a variable shows high insignificance in the model (such as P-value ≥ 0.7), it might be excluded from the final model.

According to the P-value of each independent variable, the cells of significance were painted in different colours (**Figure B.1**). The meaning of colour is applied in all the tables and figures in this study.

At 0.05 level of significance
At 0.1 level of significance
Insignificant/ Not included

Figure B.1 The meaning of different colours in the models

Models relating perceived ratings and objective measures of the street environment

Model 1 and 4 explaining perceptions on Attractive and Enjoyable

	Model 1		**Model 4**	
Dependent variable	**Attractive**		**Enjoyable**	
Adjusted R Square	0.308		0.320	
Independent variables	Coef.	Sig.	Coef.	Sig.
(Constant)	5.062	< 0.001	5.525	< 0.001
The percentage of large vehicles	0.665	0.424	0.719	0.320
Quality of pavement	0.388	0.002	0.340	0.002
Density of cycle parking	-0.120	0.039	-1.101	0.045
Maximum width of carriageway	-0.051	0.008	-0.057	0.001
Density of park	-0.286	0.743	-0.663	0.381
Density of sideroad	0.123	0.021	0.085	0.064
Office	0.044	0.004	0.033	0.011
Recreational	0.021	0.101	0.017	0.131
Transport	-0.068	0.205	-0.059	0.207

Model 2 explaining perceptions on Clean air

Model 3		
Dependent variable	**Clean air**	
Adjusted R Square	0.271	
Independent variables	Coef.	Sig.
(Constant)	4.766	< 0.001
Maximum width of carriageway	-0.053	< 0.001
PM10 (logarithmic form)	0.809	0.001
Retail	-0.019	0.079

Model 3 explaining perception on Noise

Model 3		
Dependent variable	**Noise**	
Adjusted R Square	0.235	
Independent variables	Coef.	Sig.
(Constant)	15.339	< 0.001
The percentage of large vehicles	-1.298	0.238
Traffic noise	-0.187	0.001
Pedestrian flow	0.024	0.073
Density of trees	0.045	0.149
Retail	0.021	0.243
Office	0.050	0.010
Transport	-0.113	0.086

Model 5 explaining perception on Easy to cross

Model 5		
Dependent variable	**Easy to cross**	
Adjusted R Square	0.358	
Independent variables	Coef.	Sig.
(Constant)	8.148	< 0.001
Motorised traffic volume (logarithmic form)	-0.928	< 0.001
The percentage of large vehicles	1.736	0.048
Speed of motorised traffic	-0.006	0.495
Quality of pavement	0.217	0.086
Pedestrian flow (logarithmic form)	0.211	0.391
Density of cycle parking	-0.066	0.256
Density of parking and loading bays	0.887	0.012
Density of total collision	-0.131	0.006

Model 6 explaining perception on Stop sit or rest

Model 6		
Dependent variable	**Stop sit or rest**	
Adjusted R Square	0.154	
Independent variables	Coef.	Sig.
(Constant)	3.595	< 0.001
Density of resting points	0.306	0.010
Presence of shelter at bus stop	0.499	0.090
Retail	-0.008	0.728
Office	0.058	0.018

Model 7 explaining perception on Shelter

Model 7		
Dependent variable	**Shelter**	
Adjusted R Square	0.131	
Independent variables	Coef.	Sig.
(Constant)	3.550	< 0.001
Density of trees	-0.046	0.157
Density of shelter	0.106	0.010
Presence of shelter at bus stop	0.542	0.029

Model 8 explaining perception on Safe from crime

Model 8		
Dependent variable	**Safe from crime**	
Adjusted R Square	0.280	
Independent variables	Coef.	Sig.
(Constant)	7.668	< 0.001
Motorised traffic volume (logarithmic form)	-0.338	0.038
Density of lighting columns	-0.116	0.005
Quality of pavement	0.432	< 0.001
Density of street crimes (logarithmic form)	-0.207	0.324
Recreational	0.014	0.194
Transport	0.050	0.272

Model 9 explaining perception on Intimidated by traffic

Model 9		
Dependent variable	**Intimidated by traffic**	
Adjusted R Square	0.427	
Independent variables	Coef.	Sig.
(Constant)	7.433	< 0.001
Motorised traffic volume (logarithmic form)	-0.850	< 0.001
The percentage of large vehicles	2.008	0.023
Speed of motorised traffic	-0.005	0.604
Quality of pavement	0.274	0.046
Density of parking and loading bays	0.884	0.014
Density of total collision	-0.165	0.001
Maximum geometry of curve of sideroad	-0.001	0.032

Model 10 explaining perception on Green spaces

Model 10		
Dependent variable	**Green spaces**	
Adjusted R Square	0.273	
Independent variables	Coef.	Sig.
(Constant)	4.227	< 0.001
Density of trees	0.175	0.001
Density of park	4.072	0.013

Model 11 explaining perception on Pavement quality

Model 11		
Dependent variable	**Pavement quality**	
Adjusted R Square	0.368	
Independent variables	Coef.	Sig.
(Constant)	3.822	< 0.001
Minimum width of pavement	0.099	0.100
Quality of pavement	0.671	< 0.001

Model 12 explaining perception on Good to walk

Model 12		
Dependent variable	**Good to walk**	
Adjusted R Square	0.414	
Independent variables	Coef.	Sig.
(Constant)	4.452	0.006
The percentage of large vehicles	-0.384	0.519
Traffic noise	-0.025	0.322
Density of lighting columns	-0.012	0.697
Quality of pavement	0.317	< 0.001
Pedestrian flow (logarithmic form)	0.359	0.042
Density of cycle parking	-0.026	0.501
Density of bus stop	-0.253	< 0.001

Model 13 explaining perception on Good to cycle

Model 13		
Dependent variable	**Good to cycle**	
Adjusted R Square	0.440	
Independent variables	Coef.	Sig.
(Constant)	4.454	< 0.001
Motorised traffic volume (logarithmic form)	-1.000	0.011
The percentage of large vehicles	1.329	0.238
Speed of motorised traffic	0.014	0.114
Cycle volume (logarithmic form)	0.263	0.035
Presence of cycle lane	0.484	0.019
Density of trees	-0.050	0.231

Models accounting for measured pedestrian volumes on each street

Results of basic regression model

	Model 1	
Dependent variable	**Number of pedestrians above 18 years old**	
Adjusted R Square	0.582	
Independent variables	Coef.	Sig.
(Constant)	-0.036	0.930
Attractiveness	0.097	0.024
ease to crossing road	-0.075	0.048
Percentage of not raining days	0.001	0.636
Average population density	14.730	0.048
Dummy of PTAL	0.195	0.035
Dummy of railway station	0.154	0.033
Shannon's Diversity Index (SHDI)	0.105	0.481
Residential use area	-0.148	0.125
Office use area	0.111	0.316
General and mixed retail area	0.172	0.004
Community use area	0.033	0.894
Recreational use area	0.199	0.072

Results of age segmented regression models

	Model 2		Model 3		Model 4	
Dependent variable	**Number of pedestrians**					
	18-44 years old		**45-64 years old**		**65+ years old**	
Adjusted R Square	0.623		0.532		0.378	
Independent variables	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
(Constant)	-0.520	0.198	-0.405	0.354	-0.718	0.149
Attractiveness	0.116	0.007	0.089	0.041	0.035	0.418
ease to crossing road	-0.071	0.044	-0.073	0.084	-0.042	0.258
Percentage of not raining days	0.003	0.343	-0.001	0.824	0.001	0.730
Average population density	17.853	0.012	12.549	0.129	5.875	0.539
Dummy of PTAL	0.172	0.051	0.268	0.010	0.195	0.105
Dummy of railway station	0.169	0.014	0.128	0.108	0.120	0.196
Shannon's Diversity Index (SHDI)	0.036	0.796	0.216	0.196	0.170	0.382
Residential use area	-0.165	0.072	-0.129	0.233	-0.169	0.171
Office use area	0.127	0.235	0.068	0.575	0.097	0.493
General and mixed retail area	0.180	0.001	0.144	0.027	0.140	0.059
Community use area	-0.069	0.771	0.189	0.501	0.253	0.432
Recreational use area	0.210	0.047	0.175	0.152	0.198	0.162

Results of gender segmented regression models

	Model 5		Model 6	
Dependent variable	**Number of pedestrians**			
	Male		**Female**	
Adjusted R Square	0.588		0.536	
Independent variables	Coef.	Sig.	Coef.	Sig.
(Constant)	-0.703	0.074	-0.603	0.166
Attractiveness	0.083	0.054	0.068	0.094
ease to crossing road	-0.027	0.305	-0.003	0.926
Percentage of not raining days	0.003	0.261	0.002	0.549
Average population density	11.526	0.100	10.416	0.194
Dummy of PTAL	0.209	0.020	0.229	0.025
Dummy of railway station	0.137	0.043	0.116	0.138
Shannon's Diversity Index (SHDI)	0.122	0.398	0.071	0.668
Residential use area	-0.213	0.029	-0.183	0.101
Office use area	0.138	0.197	0.134	0.268
General and mixed retail area	0.124	0.024	0.164	0.010
Community use area	-0.042	0.862	0.144	0.608
Recreational use area	0.198	0.064	0.203	0.098