Benchmarking real and ideal cities - a multicriteria analysis of city performance based on urban form

Supplemental Material

1. Evaluation of active travel probability

Evaluation of active travel probability from origin-to-destination (OD) follows the methodology of (Monteiro et al., 2023). The discussion below summarizes the methodology and follows that reference closely. Based on the OD distance, a probability for carrying out the trip in active mode, i.e., either by walking or cycling, is calculated as follows.

First, trip probability for individual walking and cycling modes is modelled via a log-logistic distribution:

$$p(x) = \frac{1}{1 + \exp(a + b \ln x)} \quad (1)$$

where a, b are parameters and x the network distance for the respective travel mode. Log-logistic parameter values depend on destination type and can be obtained indirectly from the negative exponential law for the walk mode of Yang and Diez-Roux (Yang & Diez-Roux, 2012) by calculating the distances for which the Yang and Diez-Roux law yields 10% and 90% walk probabilities, inserting these benchmarks in eq. (1), and solving for a, b for each destination type. This yields the parameters shown in Table S1 below. Trip probabilities for the cycling mode are derived assuming that users typically spend a similar time buffer in cycling trips as in walking trips (Ton et al., 2019). However, since the distance ridden by a bicycle is longer due to its higher speed, the effect on (1) is that, for cycling, the trip probability is given simply by changing the distance by $x \to x \cdot \frac{v_{\mathrm{walk}}}{v_{\mathrm{cycle}}}$. Using the walking speed of Tobler (Tobler, 1993) and cycling speed of Parkin and Rotheram [5] yields a ratio of circa $\frac{v_{\mathrm{walk}}}{v_{\mathrm{cycle}}} \approx 0.233$.

The second step in obtaining an active trip probability requires combining walking and cycling probabilities into one single probability. This is done considering three distance regimes: short, long, and medium distances, defined respectively as distances for which walk probability < 50%, < 10%, and in-between (Monteiro et al., 2023). For short distances one has the choice to either walk or use a bicycle and the active trip probability, p_{A}, can be modelled by $p_{\mathrm{A}} = 1 - (1 - p_{\mathrm{W}})(1 - p_{\mathrm{C}})$, with p_{W} and p_{C} obtained applying eq. (1) for distances x and $0.233x$ respectively, as prescribed above. Extending this reasoning for all distances would lead to an excessively optimistic trip probability for long distances (Rijsman et al., 2019; Ton et al., 2019), so in that the simplifying assumption is made that all active trips are done cycling. Finally, trips in the medium range are modelled by a linear interpolation between the short and long distance expressions. The mathematical expression for the unified active trip probability is given in eq. (2) below:

Table S1. Log-logistic parameters for walking.

Destination type	***a_j*** **(distance: km)**	***b_j*** **(distance: km)**
Post offices	1.19225	1.83021
Sports facilities	0.05574	1.83013
Cultural organizations	1.00344	1.82990
Universities and institutes	1.07775	1.82989
Elderly care centres	1.19225	1.83021
Churches	1.00344	1.82990
High Schools	1.07775	1.82989
Shopping centres	1.19225	1.83021
Entertainment sites	1.00344	1.82990
Primary healthcare services	1.19225	1.83021
Pharmacies	1.19225	1.83021
Restaurants	1.46215	1.83009
Parks and green areas	1.00344	1.82990
Kindergartens	1.46215	1.83009
Primary schools	1.46215	1.83009
Middle Schools	1.46215	1.83009
Grocery stores	1.19225	1.83021
Supermarkets	1.19225	1.83021
Bakeries and pastries	1.46215	1.83009
Jobs	0.89627	1.83017

$$p_{\mathrm{A}}(x) = \begin{cases} 1-(1-p_{\mathrm{W}})(1-p_{\mathrm{C}}) & p_{\mathrm{W}} \geq 0.50 \\ p_{\mathrm{C}} + \dfrac{1-(1-p_{\mathrm{W}})(1-p_{\mathrm{C}})-p_{\mathrm{C}}}{0{,}5-0{,}1}(p_{\mathrm{W}}-0{,}1) & 0.10 \leq p_{\mathrm{W}} \leq 0.50 \\ p_{\mathrm{C}} & p_{\mathrm{W}} \leq 0.10 \end{cases} \quad (2)$$

Because p_{W} and p_{C} depend on destination type j, the active trip probability in the manuscript reads $p_{\mathrm{A}j}(x)$ to reflect this dependence. For further details and motivation, the reader is referred to (Monteiro et al., 2023).

2. Evaluation of neighborhood pleasantness

Physical pleasantness was obtained following the methodology of of (Sousa et al., 2023). For each layout, the study area was divided into square-shaped neighborhood units with 282 x 282 m sides. Then, for each neighborhood, average values of geometric and land use elements of were obtained from the GIS models (Google Earth imagery for real Coimbra) and converted to categorical values following the scale of Table S2 below.

Table S2. Geometric and land use elements evaluated (Sousa et al., 2023).

Variable	**Definition**	**Measurement unit**	**Scale**	**Level**
Green area	Publicly available green area in the study neighborhood	Percentage (%)	0 – 5	None
			6 – 25	Small
			26 – 60	Medium
			> 61	High
Street width	Average street width, including cycle lanes, parking space and sidewalks	Meters (m)	0 – 8	Narrow
			9 – 18	Wide
			> 19	Very wide
Nr. of floors	Average floor number of all buildings in the study neighborhood	Integer	1 – 2	House
			3 – 5	Short
			6 – 11	Medium
			12 – 37	Tall
			> 38	Skyscraper
Building distance	Average buildings side setbacks	Meters (m)	0	Compact
			1 – 14	Spaced
			> 15	Sprawled
Green private area	Average private green area	Square meters (m^2)	0 – 10	Not relevant
			> 11	Backyard

The curated data formed the input for the pleasantness evaluation calculation via the cumulative link mixed model (CLMM) of (Sousa et al., 2023). This model can be formally described by:

$$\text{logit}[P(Y_i \leq j)] = \theta_j - \sum_k \beta_k X_{ki} - u_i, \qquad \text{logit}\, p = \ln\left(\frac{p}{1-p}\right), \qquad (5)$$
$$i = 1, \dots, N, \qquad j = 1, \dots, J-1, \qquad k = 1, \dots, K$$

where:
i, j, k: indices for, respectively, the study unit, ordinal pleasantness ranks ($J = 5$), and explanatory variables ($K = 5$).
$P(Y_i \leq j)$: cumulative probability of the i-th rating falling in the j-th rank of Y.
θ_j: unstructured threshold coefficients for Y.
β_k: regression coefficients.
X_{ki}: value of k in study unit i.
u_i: random effect of the judge rating study unit i, $u \sim N(0, \sigma)$.

The CLMM regression and threshold coefficients found by (Sousa et al., 2023) are given in Table S3 below. Given the categorical values of a new study unit, these coefficients enable to obtain p_{ij}, which is the probability of neighborhood i being perceived as belonging to category j, considering a judgement bias of zero.

Table S3. CLMM regression and threshold coefficients.

Variable	**Level**	**Coefficient**
Green area	medium	-0.3790
Green area	small	-0.9644
Green area	none	-0.9157
Street width	wide	0.1737
Street width	very wide	0.8216
Number of floors	short	-0.7367
Number of floors	medium	-0.8435
Number of floors	tall	-0.9499
Number of floors	skyscraper	-1.3469
Building distance	spaced	-0.2226
Building distance	sprawled	-0.2695
Green private area	none	-0.6741
Threshold coefficient	1|2	-3.0603
Threshold coefficient	2|3	-1.6770
Threshold coefficient	3|4	-0.3823
Threshold coefficient	4|5	1.1441

Finally, for each neighborhood of each layout data was plugged-in and the average $\bar{r}_i = \sum_{j=1}^{5}\left(p_{ij} \cdot j\right)$ was calculated, which represents the expectation value of that neighborhood's physical pleasantness.

References

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