Comparative analysis of urban accessibility for people with restricted mobility

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Abstract. *In many parts of the world, the number of people with restricted mobility in cities has been increasing. These include people with disabilities, elderly citizens, pregnant women and caretakers of babies an toddlers. Information about accessibility in cities is scattered among a myriad of sources, and the lack of a centralized data source is an obstacle for strategical analysis and city planning. In this work, a methodology for comparing accessibility levels of urban areas is presented. It can be applied to compare different cities or different areas within a single city. The analysis takes into account three axes: Mobility (public and private means of transportation), Indoors (buildings and venues), and Outdoors (topographical relief, streets and sidewalks). The final result is an "Accessibility Ranking", based on which different regions can be compared. As a case study, we assessed the districts of the Municipality of São Paulo, producing a ranking for which zones offer better accessibility. In total, ten databases were collected from various sources, including different City Hall Secretariats and the* guiaderodas *mobile app, a collaborative platform for evaluating the accessibility of venues and establishments. From our results, this general method for quantitatively evaluating urban areas appropriately models the real world, serving as a tool for comparative analysis of smaller regions within a greater zone and support decision-making processes. The method can be applied to any other city or metropolitan area, as long as there is enough data available.*

1. Introduction

Urban decision-making and planning should be supported by as much data as possible. Existing techniques to collect data about population needs and urban infrastructure frequently generate qualitative data, which may not be well suited for objective analysis. A methodology for comparing different zones of an urban area in a quantitative fashion can be a valuable resource, as it can provide an objective assessment to identify critical points which demand immediate attention.

In this work, we propose such a quantitative method, focusing on a specific challenge: accessibility for people with restricted mobility. As a real use-case scenario, we consider the city of São Paulo, which has an estimated population of more than 12 million people, an is the largest city in the southern hemisphere [Forstall et al. 2009]. According to the last Brazilian census, almost 700.000 of its residents have permanent motor impairment, about a third of which having complete or severe mobility difficulties [IBGE 2010].

People with disabilities are not the only ones that benefit from infrastructure for accessibility. Elderly, obese people, children and their companion adults can also be considered to have restricted mobility. In 2011, there were over 1,300,000 inhabitants aged 60 years or more in São Paulo. This number is forecasted to increase steeply, reaching around 2 million people in 2025, and almost 3 million ten years later [Seade 2017]. Additionally, it is estimated that more than half of the city's population is overweight or obese [Prefeitura de São Paulo 2015]. Between January 2015 and December 2017, about 600,000 births were registered in São Paulo [Prefeitura de São Paulo 2018], a number that provides a rough estimation for the amount of babies and toddlers in the city, which are usually carried by adults or pushed in strollers.

Even though the raw number of people with limited mobility is very significant in São Paulo, this was not the deciding factor when selecting our study target. To create a quantitative scale, data must be available. Albeit somewhat nascent compared to some European and North American cities, an open data ecosystem for the metropolis is already in place. As described in the following sections, many databases that can be used as input for the analysis exist, encompassing transportation, the city's landscape and its buildings. These databases come from both public and private sources [Geosampa 2000, Scipopulis 2018, SPTrans 2018], including a novel crowdsourced collaborative database [guiaderodas 2018].

Results presented in this paper are also available as an interactive dashboard[1]. The webpage allows users to navigate through the city map and select layers to visualize the overall performance in each scored axis. By selecting a district, users can see its detailed scores and relative position for every aspect. Featuring graphs and tables, it is also possible to reorder districts to see the individual ranking for each feature. The source code and data have been published under the MIT License[2].

2. Related work

In this paper, our notion of *"Accessibility"* refers to the degree of safety and autonomy provided by the environment to all people [Fänge and Iwarsson 2003, Otmani et al. 2009].

Several studies have been published focusing on land-use and transportation policies [Pirie 1979, Handy and Niemeier 1997], as well as on how public and private transportation correlate with social and demographic statistics [Krempi 2004]. They are also focused on general population, not necessarily people with disabilities or restricted mobility. AMELIA [Mackett et al. 2008] is a software tool for testing the impact of urban planning policies related to mobility. Focused on socially excluded groups and people with limited mobility, their methodology takes into account public transportation and outdoor elements such as sidewalk wideness, pedestrian crossings and curb ramps. It has been in use by local authorities of the city of St Albans, in England.

[1] http://interscity.org/apps/acessibilidade/
[2] https://github.com/jbarguil/free-wheels

Pasaogullari and Doratli [Pasaogullari and Doratli 2004] have presented a qualitative method for measuring urban accessibility and utilization, applied to the city of Famagusta, in Eastern Cyprus. Church and Marston [Church and Marston 2003] have proposed a method for quantitative measurement of accessibility, taking into account surfaces, barriers, and travel modes. Their study focuses on people with disabilities and is based on an " absolute access measurement". Its major goal differs from ours in the sense the our herein proposed approach is a tool for comparative analysis only, as discussed in the following sections.

Otmani *et al.* [Otmani et al. 2009] have evaluated indoor accessibility for people in wheelchairs and limited movement using techniques of virtual reality. Their analysis focuses on determining what surfaces and indoor elements are reachable by groups with different kinds of limitations. There exist other methods for quantifying accessibility of closed environments, such as measuring pedestrian movement based a building's geometric characteristics [Jeonnong-dong and Dongdaemun-gu 2008, Thill et al. 2011], and measuring the exitability of buildings under evacuation scenarios [Vanclooster et al. 2012].

3. Methodology

The first step for comparative analysis of accessibility in urban areas is to divide the studied area into smaller zones. This can be done according to administrative organization (e.g., neighborhood/county/city borders), or geographically (e.g., defining latitude/longitude limits). A greater granularity yields more detailed results, but it comes with a cost: if too many subdivisions are defined, available data may be too shattered to allow for results with proper statistical relevance. On the other hand, if the studied area is divided in zones that are too big, results can be too generic and may not be useful.

The analysis is based on three major features: Mobility (*"going from one place to another"*), Indoor areas (buildings and venues), and Outdoor areas (geographical aspects, streets and sidewalks). Each major feature is further subdivided into subfeatures, which are scored separately for each sector of the studied area.

The Mobility axis includes all aspects related to vehicle-based transportation, i.e., (a) bus routes, stops and amount of accessible vehicles, (b) subway and train stations' location and accessibility level, (c) reserved street parking spots, (d) taxi and private vehicle usage, (e) specialized assistance services for people with disabilities (such as *Atende*[3], in São Paulo), (f) origin-destination surveys, among others [Pirie 1979, Handy and Niemeier 1997].

The second major feature studies indoor accessibility, considering public buildings, private venues that are open to the public, event sites, sport arenas, and residential buildings. When measuring the accessibility of individual buildings, it is possible to apply different techniques based on its geometry [Jeonnong-dong and Dongdaemun-gu 2008, Thill et al. 2011, Vanclooster et al. 2012], produce reports from *in loco* visits by experts, or even rely on crowd-sourced evaluations from the general populace [guiaderodas 2018]. Regardless of the chosen (or viable) approach, it is important to have a statistically significant number of rated buildings in the studied area.

[3] http://www.sptrans.com.br/passageiros_especiais/atende.aspx

The last axis takes into account outdoor elements of the city such as (a) topography/declivity, (b) asphalt/street pavement coverage, and also ones that directly affects pedestrian accessibility, as (c) pedestrian crossings and overhead bridges, (e) average people flow, (f) existence of audible signals for the visually-impaired. Sidewalks are also included in this group, specially features that hinder or support accessibility: (g) holes, cracks and steps, (h) wideness and pavement type, (i) trees, utility poles, benches and other obstacles, (j) curb ramps [Church and Marston 2003, Mackett et al. 2008].

For each subfeature, individual scores are calculated and normalized between zero (worst performance) and ten (best). Intermediate sectors are interpolated accordingly. A subdivision's tally for each major feature is the average of its marks for each subfeature, and the final score is the average of the three major grades. Subdivisions with insufficient data in any partial score are not graded and receive no final mark.

3.1. Case study: São Paulo

For studying the Municipality of São Paulo, the chosen method for subdivision was to follow the prefecture's official districts. In use by the city administration since 1992 [Prefeitura de São Paulo 1992], this choice represents a reasonable trade-off based on data availability. Larger zones generate uninformative results, and dividing the studied area by its smaller neighborhoods would result in a large number of sectors with poor statistical relevance. Information about the districts, including their georeferenced borders, was collected from the City Hall's open data portal [Geosampa 2000].

The selection of datasets used in the analysis was based on the following criteria. First, only information openly available to the public was used. Data need not be properly classified and organized, it is sufficient that it is freely available on the web. Second, data should cover the entire Municipality. Information about a single or too few zones, albeit relevant in a local or quantitative analysis, does not allow for comparison between different areas of the city.

Even though several possible sub features were initially outlined, the study is limited to the availability of information. The following datasets were collected between January and February/2018:

- Mobility.
  - **Buses**. Information about bus routes, stops, terminals and scheduled departures of accessible vehicles [Scipopulis 2018, SPTrans 2018].
  - **Subway/train stations**. Location of subway and metropolitan train stations [Geosampa 2000].
  - **Reserved street parking places**. Address and amount of street parking spots reserved for people with disabilities and elderly [Geosampa 2000].
- Indoors.
  - **"Accessibility Seal"**. A list of venues, both public and private, that have been granted the certification issued by *São Paulo City's Permanent Commission for Accessibility* [Geosampa 2000].
  - **User-generated venue ratings by guiaderodas**. A crowd-sourced database about the accessibility of several kinds of buildings and venues [guiaderodas 2018].
- Outdoors.

– **Topography/Declivity**. Denotes the inclination of slopes throughout the city [Geosampa 2000].

The next subsections describe how each data source was analyzed and their corresponding scores were calculated.

3.2. Mobility

The first evaluation criteria is urban mobility. In this analysis, we took into account the main transport modes: *buses*, *subway and trains*, and also *reserved street parking spaces*.

3.2.1. Bus lines

By law, people with disabilities and limited mobility are allowed to leave buses between stops in São Paulo [Prefeitura de São Paulo 2013]. For this reason, our analysis disregarded the geographical location of bus terminals and stops.

Not all of São Paulo's buses are accessible for people in wheelchairs. Weekly departure schedules of accessible vehicles are available at the city's bus administration website [SPTrans 2018], so it is possible to calculate the amount and proportion of accessible trips for each bus line. There exist two kinds of accessible buses in the fleet: ones with mechanical elevators, and ones with lower floor (leveled to the curb and sidewalk, allowing for easy boarding). However, mechanical elevators may be out of order, meaning that even if in theory a trip was supposed to be accessible for people in wheelchairs, it reality it may not be, due to non-functional elevators. Unfortunately, there was no data available that allowed us to account for this fact in the study.

By plotting the geographical borders of districts and the route of each of line, obtained from the Scipopulis database [Scipopulis 2018], it is possible to count the number of bus lines that cross each studied area. Because many district limits are defined by streets or avenues, bus lines that go through them are counted for both bordering districts.

By combining both numeric values, one can determine the number of accessible buses that are scheduled to go through each district in a week. The score for this subfeature is the calculated "density of accessible bus trips per week", or the sum of bus lines that cross each district, weighted by their number of accessible vehicles, and divided by the district's area. Grades are then linearly normalized.

3.2.2. Subway & Train

Subway and train are important modes of public transport in the big cities, especially for people with disabilities. Here, we describe the approach we used to measure how well a neighborhood is served by subway and train lines.

Not all stations have the same accessibility service level. However, they should provide at least minimal accessibility conditions. Due to a lack of information about the level of accessibility for each station, all stations were considered as accessible.

To measure this item, our approach was to consider that each station has a region of influence on its surroundings. This influence was defined as a Gaussian function of the haversine distance [Van Brummelen 2012] from any point to the station's geographical location. This means that a station's influence drops exponentially as distance increases. Figure 1 shows a cross section of the influence function we defined for each station.

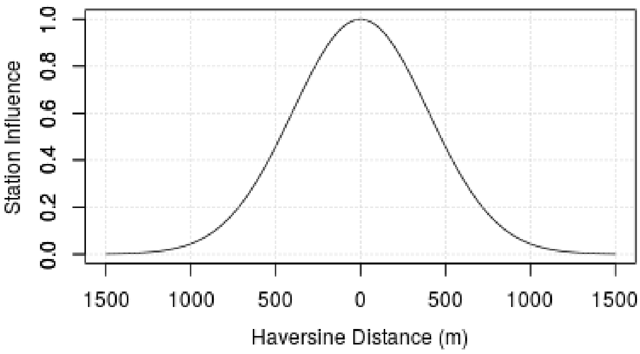

Figure 1. A station's influence function.

Once the influence function has been placed over each subway and train station, we defined a square mesh on the map with a resolution of 100m. For each point on this mesh we computed the influence level of the nearest station. Finally, we computed the average influence level over all points within the same district.

3.2.3. Reserved street parking spaces

In areas with great daily circulation of cars and people, street parking is paid and cars are allowed to stay a limited amount of time. This system, called *"Zona Azul"*, works in a similar fashion to parking meters in the United States. Several of these Zona Azul parking spots are reserved for people with limited mobility, divided in two categories: people with disabilities, and the elderly. To be able to park in these spaces, a permit card must be obtained from the City Hall, and it should be displayed on a car's windshield while parked. If the proper permit is not visible, the car may be fined and towed.

In our study, we took into account these reserved places by calculating their "average density" in each district, i.e., by counting the number of reserved spots within the district and dividing by its area. A district's score for this subfeature is obtained after grade normalization.

3.3. Indoors - Buildings and Venues

The ideal scenario to rank indoor accessibility is to have complete information about each and every building in the city. At least to the extent of our knowledge, there is no such dataset available, so the analysis was based on two sources: the list of places granted the *"Accessibility Seal"* by *São Paulo City's Permanent Commission for Accessibility* [Geosampa 2000], and the *guiaderodas* [guiaderodas 2018] database, generated by their users.

Launched in 2016, guiaderodas is an accessibility guide for people with mobility difficulties. Its mobile app lists nearby places based on user location, allowing any person to review or consult the accessibility of venues. It also features a text search for reviewing or checking places in any country. The United Nations has granted it an award for being the *"best initiative for inclusion & empowerment in the world"* [Belloni 2017, Yuge 2017]. Its database contains thousands of reviewed places in the city of São Paulo.

Users rate venues in guiaderodas by answering questions, which are presented depending on its category. For instance, all reviews include questions about the entrance and reserved/vallet parking, but users reviewing hotels can report the existence (or lack thereof) of accessible bedrooms, whereas for restaurants and coffee shops they are asked about the height of tables and counters. Not all reviews contain ratings for every criteria, as users are free to skip any question.

For each aspect, users can assign three different values, according to a color scale: *red* (bad), *yellow* (average) and *green* (good). This means that the database does not contain information about accessible places only, but also about partially or not accessible venues, making it a valuable source of information. Table 1 displays the numeric values used to map color scores into partial scores.

Color Rating	Score
Red	1
Yellow	3
Green	5

Table 1. Numeric values for crowd-sourced venue ratings.

An individual venue's score is the average of all of its user-provided ratings. Because more than half of the districts had no data at all in the Accessibility Seal dataset, this source was integrated into the guiaderodas database by applying maximum grade to each place listed in the collection.

The final score for this axis was the arithmetic average of all rated venues within each district. As a consequence of geographic bias in the amount of app users, the number of ratings in each district has high variance. To preserve statistical relevance, districts with too few data points received no score.

3.4. Outdoors - Topography

As explained in Subsection 3.1, Topography was the only Outdoor feature for which sufficient data was found. It is also an important factor in assessing accessibility in urban areas. This is a largely geographical issue, since in practice it is very difficult to change the urban topography in a macro-scale, especially in already urbanized areas. However, it is important to take the slope of the terrain into account in our analysis, since very steep areas can greatly impact people with mobility restrictions.

Terrain slope is a measurement of how steep the ground surface is. It is expressed as the percentage ratio between the *rise* and *run* distances, as shown in Figure 2. In short, the steeper the surface, the greater the slope. The studied dataset classifies areas in four slope categories, according to Table 2.

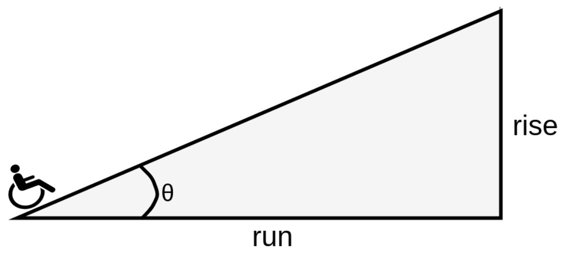

Figure 2. Slope measurement.

Area	Description	Weigth
1	up to 5.0%	0
2	from 5.0% to 25.0%	5
3	from 25.0% to 60.0%	25
4	greater than 60.0%	60

Table 2. Terrain slope categories and weights.

We assigned a weight for each slope category, which corresponds to the lowest value of the slope range of each class. Accordingly, the topography score can be computed by a weighted average, which considers the class weight and the percentage of district's area classified in each category (equation 3.4).

$$topography\_score = \frac{0 * area_1 + 5 * area_2 + 25 * area_3 + 60 * area_4}{area_1 + area_2 + area_3 + area_4}$$

Thus, the value of $topography\_score$ is larger for districts with bigger fractions of their area classified into steeper categories. The final topography score is obtained after linear normalization between 0.0 (worst performance) and 10.0 (best).

4. Results and Discussion

Table 3 contains the total score for each city zone, calculated as the average score of its districts. Districts without final score were not taken into account. A detailed table with all partial scores per district is available in the Appendix. Figure 3 presents results as a color-scaled map.

	Zone	**Districts**	**Indoors**	**Topography**	**Mobility**			**Total**
					Bus	Parking	Subway	
1	Central (C)	8	6.7685	8.5622	8.3940	9.2626	6.2127	7.7624
2	West (W)	15	7.3105	7.9030	6.4906	3.4456	2.4769	6.6239
3	South (S)	33	6.6714	6.7175	6.0391	2.7474	1.4575	5.7620
4	East (E)	22	5.5156	7.2920	6.6926	2.8571	1.5360	5.6242
5	North (N)	18	5.8541	5.2256	5.5868	1.1833	0.6743	4.6355

Table 3. Average district scores, per zone.

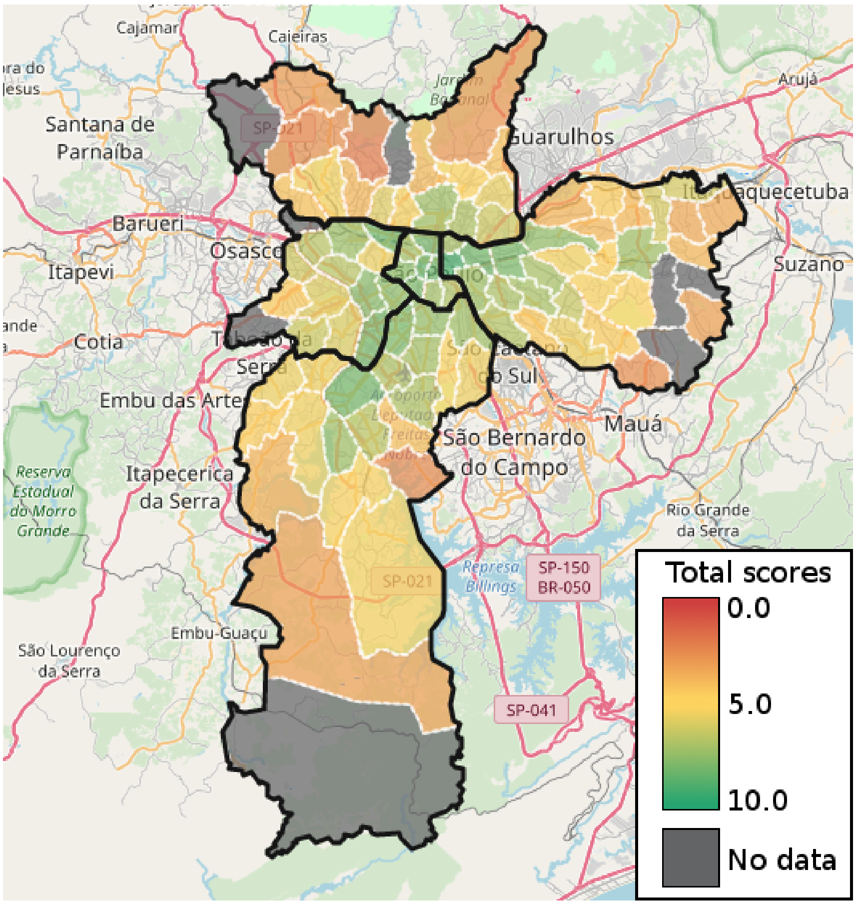

Figure 3. Final scores per district.

Indoor scores have a noticeably better average performance in the West Zone. Considering that it contains many of the districts which also have better Human Development Index (HDI) scores [Prefeitura de São Paulo 2007], this result seems to be in accordance to the qualitative perception that, in general, its buildings have better accessibility. As mentioned in Subsection 3.3, a geographic bias has been noticed in the database, meaning that the distribution of rated venues is not uniform across the districts. Therefore, it was necessary to set a minimum quantity of data points per district, excluding ones that did not have enough data. Such districts received no score for this axis and are not included in Table 3.

Topography scores translate the peculiarity of São Paulo's geography. The city is crossed by two major rivers, Tietê and Pinheiros, and districts near the historical floodplains tend to have low average declivity. Additionally, the area where the city was founded in the XVI century is also rather flat, justifying the high average score of the Central Zone. In the outskirts of the city, mountain ranges exist, specially in the extreme north and south (*Cantareira* and *Sea* ridges, respectively). This causes a much worse performance for districts in these areas, which inflates the score of flatter regions. After linear normalization, the average score of this axis was the highest – only 16 of the 96 districts received a grade below 5.0.

Mobility results show the high centralization of São Paulo's public transportation infrastructure. In general, most of the bus routes connecting North/South and East/West zones necessarily cross the city center. For subway and train lines, this characteristic is even more apparent: 4 of the 5 existing subway lines go through several stops in the Central Zone, causing a "high density" of stations in this area. In São Paulo, priority parking spaces for people with disabilities and elderly citizens only exist in streets with high daily circulation of automobiles and people. Once again, an extreme concentration around the city center can be observed. In fact, almost two thirds of the districts received grade zero for this aspect, meaning that there is no reserved parking whatsoever in these parts of the city. These facts explain the good overall performance of central districts in this feature. Considering that the goal of the Mobility axis is to measure which areas offer more versatility for transportation, numeric results seem to satisfactorily approximate the observed reality.

In general, results show that the districts with the best accessibility score are strongly correlated with the central areas (specially due to Mobility factors) and regions with higher socioeconomic indicators. Considering that this is in accordance to the preexisting qualitative perception, the model can be held to satisfactorily represent the observed reality.

4.1. Limitations

It is important to highlight that due to the nature of our comparative scale, a single isolated score does not support any kind of conclusion. A final district's mark of 8.0, for instance, does tell if the district is accessible or not. It means that, according to studied parameters and data, it has *better* accessibility than districts with lower score.

As a consequence, two separate studies with this method yield completely independent results that do not allow for comparisons between each other, as grades are not akin nor interchangeable.

4.2. Future Work

The evaluation criteria used in this work can still be further developed in future research by improving both quality and quantity of analyzed data. This includes: expanding existing datasets, aggregating new datasets for other subfeatures listed in Section 3, and taking into account the geographic distribution of people with limited mobility (i.e., *"where they live"*).

Another path for improvement is to create guidelines to compare the relevance of each feature and subfeature. In our case study, we considered that all datasets had equal importance and final scores were a simple arithmetic average. For a better model of the real world, one should be able to give greater weights to aspects considered more significant in the generation of the final ranking. This can be achieved by creating a group of rules to set the relevance of each subfeature. Ideally, this rule set should be flexible and allow for proper parametrization to accommodate different realities observed in different urban zones.

Finally, this work can also serve as a starting point for the creation of an *absolute* accessibility scale. Such grading method would allow for drawing conclusions from isolated scores, instead of the purely comparative nature of our current method. This would solve the method's biggest drawbacks, explained in Subsection 4.1.

5. Concluding Remarks

In this paper we proposed a general method for quantitatively evaluating urban areas regarding the accessibility of services and infra-structure for people with mobility difficulties. We also presented a case study to exemplify the method's application. Several publicly available datasets about the city of São Paulo were used to support our survey.

Obtained results seem to achieve the intended goal: to effectively model the real world, serving as a tool for comparative analysis of smaller regions within a greater zone and support decision-making processes. The method can be applied to any other city or metropolitan area, as long as there is enough data available.

The suggested metrics to assess urban areas with respect to accessibility can be further extended and refined, as well as adapted according to different urban settings, availability and reliability of data sources. Our goal with this work is to build good foundations based on which a general platform and methodology for assessment of structural aspects of urban design can be developed.

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References

Belloni, L. (2017). Brasileiro ganha prêmio da ONU por app que avalia acessibilidade de estabelecimentos no país e no mundo. `https://goo.gl/9CMCdo`. [accessed in February/2018].

Church, R. L. and Marston, J. R. (2003). Measuring accessibility for people with a disability. *Geographical Analysis*, 35(1):83–96.

Fänge, A. and Iwarsson, S. (2003). Accessibility and usability in housing: construct validity and implications for research and practice. *Disability and Rehabilitation*, 25(23):1316–1325.

Forstall, R. L., Greene, R. P., and Pick, J. B. (2009). Which are the largest? Why lists of major urban areas vary so greatly. *Tijdschrift voor economische en sociale geografie*, 100:277—297. DOI: 10.1111/j.1467-9663.2009.00537.x.

Geosampa (2000). Sistema de consulta do mapa digital da cidade de São Paulo. `http://geosampa.prefeitura.sp.gov.br/`. [accessed in February/2018].

guiaderodas (2018). guiaderodas: Empresa de acessibilidade. `https://guiaderodas.com`. [accessed in February/2018].

Handy, S. L. and Niemeier, D. A. (1997). Measuring accessibility: An exploration of issues and alternatives. *Environment and Planning A: Economy and Space*, 29(7):1175–1194.

IBGE (2010). Censo demográfico, amostra - pessoas com deficiência. https://cidades.ibge.gov.br/brasil/sp/sao-paulo/pesquisa/23/23612/. [accessed in February/2018].

Jeonnong-dong and Dongdaemun-gu (2008). Indoor spatial analysis using space syntax. *ISPRS Silk Road for Information from Imagery*, pages 1065–1069.

Krempi, A. P. (2004). Exploring spatial statistics tools for an accessibility analysis in the city of Bauru. Master's thesis, Escola de Engenharia de São Carlos. [accessed in February/2018].

Mackett, R. L., Achuthan, K., and Titheridge, H. (2008). AMELIA: A tool to make transport policies more socially inclusive. *Transport Policy*, 15(6):372–378.

Otmani, R., Moussaoui, A., Pruski, A., et al. (2009). A new approach to indoor accessibility. *International Journal of Smart Home*, 3(4):1–14.

Pasaogullari, N. and Doratli, N. (2004). Measuring accessibility and utilization of public spaces in Famagusta. *Cities*, 21(3):225 – 232.

Pirie, G. H. (1979). Measuring accessibility: A review and proposal. *Environment and Planning A: Economy and Space*, 11(3):299–312.

Prefeitura de São Paulo, Secretaria de Saúde. (2015). Inquérito de Saúde da Capital - ISA Capital.

Prefeitura de São Paulo, Secretaria do Trabalho e Empreendedorismo. (2007). Atlas do Trabalho de Desenvolvimento da Cidade de São Paulo.

Prefeitura de São Paulo (1992). Lei nº 11.220.

Prefeitura de São Paulo (2013). Lei nº 15.914.

Prefeitura de São Paulo (2018). TabNet - Secretaria de Saúde. http://tabnet.saude.prefeitura.sp.gov.br/cgi/tabcgi.exe?secretarias/saude/TABNET/sinasc/nascido.def. [accessed in February/2018].

Scipopulis (2018). Scipopulis - construindo conhecimento. https://scipopulis.com. [accessed in February/2018].

Seade, F. (2017). Projeção da população por faixas etárias quinquenais do município de são paulo. ftp:/http://produtos.seade.gov.br/produtos/projpop/index.php. [accessed in February/2018].

SPTrans (2018). Olho vivo SPTrans. http://olhovivo.sptrans.com.br. [accessed in February/2018].

Thill, J.-C., Dao, T. H. D., and Zhou, Y. (2011). Traveling in the three-dimensional city: applications in route planning, accessibility assessment, location analysis and beyond. *Journal of Transport Geography*, 19(3):405–421.

Van Brummelen, G. (2012). *Heavenly mathematics: The forgotten art of spherical trigonometry*. Princeton University Press.

Vanclooster, A., Neutens, T., Fack, V., Van de Weghe, N., and De Maeyer, P. (2012). Measuring the exitability of buildings: A new perspective on indoor accessibility. *Applied Geography*, 34:507–518.

Yuge, C. (2017). App nacional para acessibilidade de cadeirantes vence prêmio global da onu. https://goo.gl/tGdMSx. [accessed in February/2018].

Appendix

Table 4 displays each district's final score for each analysed aspect.

	District (Zone)	Indoors	Topography	Mobility			Total
				Bus	Parking	Subway	
1	Brás (E)	8.9678	10.0000	8.2026	9.9478	7.0600	9.1238
2	República (C)	7.1981	9.0139	9.5931	10.0000	9.1583	8.5986
3	Sé (C)	6.5024	8.8656	10.0000	9.8820	10.0000	8.4429
4	Barra Funda (W)	8.8366	9.6899	7.4515	7.8462	4.1212	8.3331
5	Belém (E)	8.5266	9.6832	7.8384	8.2982	3.0432	8.2010
6	Santo Amaro (S)	9.6214	9.0258	7.9655	6.3589	3.4356	8.1891
7	Bom Retiro (C)	7.1954	9.8676	7.3120	9.5125	5.6605	8.1860
8	Itaim Bibi (W)	8.4577	9.8279	7.1126	9.1278	2.4399	8.1708
9	Bela Vista (C)	8.6106	7.1390	8.8633	9.4396	6.8864	8.0487
10	Tatuapé (E)	8.2186	9.4290	7.5035	8.0805	3.6897	8.0240
11	Moema (S)	8.8442	9.6061	7.6009	9.1940	0.0544	8.0222
12	Pinheiros (W)	6.6238	9.0581	7.8187	9.1627	5.8688	7.7662
13	Jardim Paulista (W)	7.1239	8.7706	8.0134	9.6033	3.7969	7.6774
14	Consolação (C)	7.6892	7.7326	7.7919	9.9017	5.0511	7.6678
15	Penha (E)	8.6992	7.8027	7.4625	7.5535	2.7631	7.4761
16	Vila Mariana (S)	6.9935	7.6956	7.6589	9.0050	6.2814	7.4459
17	Lapa (W)	6.7660	8.6128	7.0249	8.3909	3.7455	7.2553
18	Socorro (S)	7.1976	9.4562	6.9439	6.5742	1.5179	7.2219
19	Mooca (E)	6.8723	8.7969	6.7616	8.0967	3.0615	7.2142
20	Santana (N)	7.1155	8.2743	7.0345	7.6163	3.8040	7.1804
21	Itaquera (E)	8.8604	7.0979	7.4250	7.0185	2.2466	7.1739
22	Santa Cecília (C)	4.6467	9.4983	7.8063	8.7151	5.4471	7.1559
23	Ipiranga (S)	6.5856	8.8110	6.7358	7.6092	3.7936	7.1476
24	Liberdade (C)	6.5584	7.5215	8.1285	8.4459	5.2268	7.1157
25	Saúde (S)	7.0454	7.8611	6.7112	7.8024	4.6935	7.1030
26	Pari (E)	4.7934	9.9685	7.3663	9.6505	1.4944	6.9774
27	Vila Formosa (E)	8.8154	7.1578	6.7982	7.8944	0.0096	6.9580
28	Carrão (E)	9.9655	8.5261	6.8991	0.0000	0.2392	6.9570
29	Água Rasa (E)	8.5841	7.7545	6.5662	5.9307	0.8339	6.9274
30	Cambuci (C)	5.7474	8.8590	7.6572	8.2043	2.2716	6.8836
31	Jabaquara (S)	8.6557	6.8783	6.1742	6.4582	2.2969	6.8368
32	Campo Belo (S)	7.0753	8.4275	7.5145	7.4400	0.0305	6.8326
33	Vila Guilherme (N)	8.9332	8.8822	6.7286	0.0000	0.4648	6.7377
34	Vila Prudente (E)	6.1092	8.1287	6.7755	7.2929	3.3173	6.6777
35	Alto de Pinheiros (W)	8.4855	8.4076	5.8826	0.0000	2.5676	6.5699
36	Vila Leopoldina (W)	6.5186	9.5003	6.3147	0.0000	4.7236	6.5661
37	Campo Grande (S)	8.6704	8.2941	6.8046	0.0000	1.0923	6.5323
38	Aricanduva (E)	8.0661	7.9893	7.6046	0.0000	0.0000	6.1968
39	Vila Sônia (W)	10.0000	6.3099	6.2694	0.0000	0.0000	6.1333
40	Vila Maria (N)	7.5469	8.8271	5.6808	0.0000	0.0004	6.0892
41	Jaguaré (W)	7.6243	7.6522	5.5822	0.0000	2.7983	6.0233
42	Jardim Helena (E)	5.2923	9.9521	4.5307	0.0000	2.8703	5.9038
43	São Miguel (E)	3.4040	8.4264	7.4120	7.9429	2.0583	5.8783
44	Morumbi (W)	8.3303	6.4307	5.9870	0.0000	2.2985	5.8409
45	Limão (N)	6.9449	7.8858	6.7339	0.0000	0.0017	5.6920
46	Butantã (W)	6.4648	7.7981	6.4196	0.0000	1.9135	5.6802
47	Vila Medeiros (N)	3.0371	8.7564	6.1972	7.2970	0.0037	5.4309

	District (Zone)	Indoors	Topography	Bus	Parking	Subway	Total
48	Sapopemba (E)	7.7553	6.2571	6.5774	0.0000	0.0000	5.4016
49	Perdizes (W)	4.0185	6.5731	6.7239	7.5531	2.5578	5.4011
50	Campo Limpo (S)	8.2077	5.2280	6.6516	0.0000	1.4334	5.3769
51	Vila Andrade (S)	8.8096	4.4472	6.4087	0.0000	2.2129	5.3769
52	Sacomã (S)	6.7308	7.3734	5.4297	0.0000	0.2303	5.3303
53	Jardim São Luis (S)	6.7711	6.5665	6.4659	0.0000	0.9361	5.2683
54	Vila Matilde (E)	5.2948	7.3066	6.1868	0.0000	3.4023	5.2659
55	Pirituba (N)	8.2185	4.5260	5.6152	0.0000	2.7645	5.1792
56	Grajaú (S)	7.1423	6.7264	4.8120	0.0000	0.1006	5.1688
57	Casa Verde (N)	5.8679	7.2872	6.6526	0.0000	0.0060	5.1249
58	Cursino (S)	6.1061	7.0124	5.6791	0.0000	0.8457	5.0978
59	Cidade Dutra (S)	5.2370	7.4058	6.1133	0.0000	1.5598	5.0668
60	Cidade Líder (E)	7.4790	5.4505	6.6487	0.0000	0.0249	5.0514
61	Parque do Carmo (E)	8.4209	4.6188	5.9003	0.0000	0.0004	5.0022
62	Artur Alvim (E)	3.9048	7.4022	7.4009	0.0000	3.2886	4.9567
63	Tucuruvi (N)	5.1847	6.6105	6.3188	0.0000	2.7969	4.9446
64	Capão Redondo (S)	6.4939	5.1885	6.8695	0.0000	1.5413	4.8287
65	São Mateus (E)	4.8286	7.1285	6.9755	0.0000	0.0000	4.7607
66	Ermelino Matarazzo (E)	3.6630	7.5800	6.2494	0.0000	2.7472	4.7473
67	Rio Pequeno (W)	5.7869	6.3629	5.7922	0.0000	0.0000	4.6935
68	São Lucas (E)	3.6014	7.6410	6.6706	0.0000	1.0142	4.6014
69	Jaçanã (N)	4.3604	6.7453	6.3728	0.0000	0.0000	4.4100
70	São Domingos (N)	5.5300	5.9093	5.0466	0.0000	0.0965	4.3846
71	Cidade Ademar (S)	5.0348	5.8003	6.6585	0.0000	0.0000	4.3515
72	Mandaqui (N)	6.6330	3.7312	5.8140	0.0000	0.0002	4.1007
73	Ponte Rasa (E)	1.7925	7.8219	7.9363	0.0000	0.0109	4.0878
74	Vila Jacuí (E)	2.1885	7.6070	7.2833	0.0000	0.0042	4.0749
75	Freguesia do Ó (N)	3.8291	6.2649	6.2879	0.0000	0.0321	4.0669
76	Lajeado (E)	2.8120	6.8612	6.4046	0.0000	1.1550	4.0644
77	Jardim Ângela (S)	5.0924	4.9216	5.0890	0.0000	0.0000	3.9034
78	Cangaíba (E)	1.0360	8.2365	5.4781	0.0000	1.7364	3.8924
79	Itaim Paulista (E)	1.0730	7.4432	5.7508	0.0000	1.3071	3.6229
80	Vila Curuçá (E)	0.0000	8.0094	6.9277	0.0000	1.0697	3.5584
81	Parelheiros (S)	3.7818	4.8389	3.5451	0.0000	0.0000	3.2675
82	Cidade Tiradentes (E)	4.0755	3.7278	5.8739	0.0000	0.0000	3.2538
83	Perus (N)	5.8214	1.9817	3.5030	0.0000	0.7924	3.0783
84	Tremembé (N)	7.3223	0.3945	3.6003	0.0000	0.0000	2.9723
85	Jaraguá (N)	4.2134	2.0122	4.8130	0.0000	1.3747	2.7627
86	São Rafael (E)	2.3680	4.0718	4.9297	0.0000	0.0000	2.6943
87	Pedreira (S)	0.0025	6.2212	5.0272	0.0000	0.0092	2.6342
88	Brasilândia (N)	3.1080	1.0752	5.5746	0.0000	0.0000	2.0138
-	Anhanguera (N)	-	1.8401	2.2314	0.0000	0.0000	-
-	Cachoeirinha (N)	-	3.0568	6.3568	6.3860	0.0000	-
-	Guaianases (E)	-	5.3328	6.7099	6.5771	1.1588	-
-	Iguatemi (E)	-	2.1634	5.2813	0.0000	0.0000	-
-	Jaguara (W)	-	8.0224	5.8091	0.0000	0.3225	-
-	José Bonifácio (E)	-	5.2635	6.5253	0.0000	1.0798	-
-	Marsilac (S)	-	0.0000	0.0000	0.0000	0.0000	-
-	Raposo Tavares (W)	-	5.5289	5.1573	0.0000	0.0000	-

Table 4: Final scores by district.