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PROPOSAL OF A SIDEWALK ACCESSIBILITY INDEX

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Abstract: This paper describes an indicator to evaluate the performance of the infrastructure of sidewalks and public spaces, based on the expectations and perceived needs of wheelchair users, aiming to define accessible routes along urban road networks. The indicator considers variables that describe aspects of comfort and safety for disabled wheelchair users, weighted according to the perception of such users. The application of the indicator in the evaluation of the downtown area of a medium-sized Brazilian city confirmed the hypothesis that there are no accessible routes and helped identify locations where interventions or modifications of already implemented improvements are required to enable the wheelchair user to circulate easily through the city.

Keywords: Accessibility, wheelchair users, sidewalk accessibility

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INTRODUCTION

The sidewalks of most Brazilian cities, where they actually exist, are precarious, representing discomfort and lack of safety for pedestrians in general and for the disabled in particular. A preliminary evaluation of these sidewalks indicates that most of them are unsuitable for proper circulation because of the presence of obstacles, their precariousness, or the unsuitability of the materials used in their construction.

Some of the physical characteristics of these sidewalks may go unnoticed or may be easily overcome by people whose physical mobility is unrestricted, but for people with physical disabilities, these characteristics often pose real obstacles that end up segregating or resulting in discrimination against them, denying these individuals free access to the use of public spaces.

For many years, the physical and personal characteristics and difficulties in mobility of physically disabled people have explained their social maladjustment. However, numerous theories and concepts in various fields of knowledge today seek to link human behavior to the physical environment. While some lines of reasoning emphasize the need for people to adapt to environmental circumstances, others, in contrast, see in the environment the causes for certain human conflicts (Cohen & Duarte, 2001). Based on the second principle, one can see that it is not people who are disabled, but rather, buildings, transport systems, parks, and cities in general, that are inefficiently planned and designed for use by a diversity of humans (not just for a standard man).

Today, with the effective participation of organized groups and nongovernmental organizations in issues relating to the structuring of urban policies, measures are beginning to be adopted to promote the real participation and integration of disabled people in society. One can already see the action of some local administrations in the development of specific programs and projects, especially with regard to the adaptation of built urban environments.

Some Brazilian municipalities already have experiences with projects and programs implemented to facilitate the access of disabled people in urban spaces, and these experiences can serve as the basis for new ways and strategies to solve this problem of social exclusion once and for all. These experiences include solutions for access to public transportation, adaptations to improve accessibility by means of ramps, modifications of urban furniture and fittings, and parking spaces for the disabled.

The problem is that all these interventions involve isolated actions rather than being part of an overall plan for improving the city to facilitate the circulation of people, including those with any type of mobility disability. It is not enough to simply execute projects and works aimed at facilitating the lives of disabled people. Instead, cities should have guidelines for the implementation of accessibility programs which, from the standpoint of the physically disabled, allow one to evaluate whether the urban interventions, the available means of transportation, and the adaptations implemented in public or private buildings favor the creation of "accessible routes" that really enable access to a variety of points in the city.

The diversity of individual limitations is one of the difficulties in proposing routes that are accessible to everyone. A universally accessible environment should be the sum of environments accessible to each individual. Three large population groups can be identified with special needs in terms of movement: the elderly and people with partial mobility limitations, the wheelchair-bound, and people with sensory limitations. There are no absolute levels that ensure accessibility for all. Moreover, the adaptations required may be extremely costly or technologically complex.

The pedestrian environment often presents obstacles for the movement of wheelchair-bound people. The problems usually result from inadequate design or construction, deficient maintenance, or even natural characteristics of the terrain. The absence of sidewalks that are properly paved and maintained restricts the mobility of people with the most varied sorts of limitations. Uneven surfaces, garbage, vegetation and curbs without ramps often force people to use the street bed, thus increasing their vulnerability.

According to the Brazilian standard NBR 9050/94, an accessible route is "a continuous, unobstructed trajectory with signs linking external environments or internal spaces and buildings, which can be used autonomously and safely by everyone, including people with disabilities or reduced mobility. On public streets and roads, this route may incorporate parking spaces, lowered sidewalks, pedestrian crossings, ramps, etc."

In this context, this paper describes an indicator which, based on the expectations and perceived needs of wheelchair users, serves to evaluate the performance of the infrastructure of public spaces, aiming to define accessible routes along the urban network of cities. The indicator considers variables that describe aspects of comfort and safety for wheelchair users, weighted according to the perception of those users.

ACCESSIBILITY FOR WHEELCHAIR USERS

The literature contains several studies analyzing the factors and barriers interfering in the accessibility of wheelchair users during their movement through urban spaces.

A relevant study of wheelchair accessibility was reported by Chesney & Axelson (1996), who developed a method to objectively measure the effort of a wheelchair-bound person moving over different types of surfaces. An important conclusion of that study was that the effort required to overcome a given ramp slope can be represented by a "pass/not pass" criterion when it involves a short distance (the entrance to a garage, for instance). However, the authors concluded that it is necessary to evaluate the impact when the distances involved are long (e.g., to navigate over a long stretch of sidewalk). They propose a measure of performance for sidewalk accessibility that can be divided into the following stages: (1) divide the route into several stretches whose limits are defined by changes in transversal and longitudinal downhill grade; (2) multiply the length of each stretch by the effort needed per meter to cover it; (3) add up the values obtained for all the stretches; and (4) normalize the result to a value of effort per mile. The value thus obtained can be compared with a critical value obtained through a research with a sampling of wheelchair users and can be used together with a critical admissible value for short distances.

Petzall (1996) described research conducted in Sweden to define the height of steps that can be traversed by a wheelchair with the help of a pedestrian. His results indicated that in public spaces where a wheelchair user can find help, 5 cm high steps are acceptable. Ten cm high steps may be acceptable if there is sufficient space to maneuver the wheelchair so that the most convenient position can be found to overcome the obstacle. Steps higher than 10 cm should be avoided.

Beale *et al.* (2000) propose a GIS (Geographic Information System) aimed at providing the wheelchair user with a tool to select accessible routes in the urban environment. The system determines the optimal route for the user based on the cumulative hindrances caused by the urban barriers and considering personal preferences (e.g., avoiding ramps with slopes exceeding 4%).

Kockelman *et al.* (2000) identified the following factors that affect the perception of comfort (for the disabled) when traveling on a sidewalk:

- length of a continuous stretch of sidewalk exceeding 2% of cross slope;
- proportion of the total length of the sidewalk exceeding 2% of cross slope;
- volume of vehicle traffic on the adjoining road and distance of separation from that traffic;
- condition of the sidewalk pavement (type, texture, state of maintenance);
- longitudinal downhill grade of the sidewalk (uphill and downhill grades affect the user differently);
- climate;
- width of the sidewalk;
- degree of accessibility of the entire route (including lowered curbstones, street crossings, etc.).

Kockelman *et al.* (2002) conducted a study to determine the maximum admissible cross slope for a sidewalk, seeking to determine if the value traditionally accepted as the maximum (2%) was effectively the critical value. Their study found that transversal declivities in the order of 5.5 to 6% can be admissible for wheelchair users provided the longitudinal downhill grade of the sidewalk is less than 5%.

Oeda & Sumi (2003) proposed a method to evaluate the roughness of sidewalks and pavement cracks from the point of view of wheelchair users. The perceived level of discomfort is recorded on a scale of 1 to 5 (the higher the value, the greater the discomfort). These researchers identified a function that correlates the level of vibration with the level of discomfort.

Ishida *et al.* (2006) analyzed the longitudinal profile of sidewalks in order to propose a method for evaluating the surface unevenness of sidewalks based on the travel resistance imposed on wheelchairs. The study revealed a strong correlation between surface unevenness values calculated by the proposed method and discomfort rating by panel members.

The objective of the research carried on by Richter *et al.* (2007) was to test the hypothesis that pushing on a cross slope leads to increased handrim loading compared with that found on a level surface. The authors concluded that users must push harder when on a cross slope. The increased loading is borne by the users' arms, which are at risk for overuse injuries. The power required for propulsion increased by a factor of 2.3 on a 6° cross slope.

A Brazilian publication (CPA/SEHAB, 2003) describes all the characteristics an accessible public route should possess in order to provide mobility and accessibility to all users, ensuring access principally to the elderly, disabled and people with limited mobility.

METHODOLOGY

The methodology employed in the present study to devise an indicator to evaluate the performance of the infrastructure of sidewalks, crossings at street intersections and public spaces, based on the expectations and needs of physically disabled, wheelchair-bound people includes the following stages:

- Technical evaluation, based on a qualitative analysis of the variables that physically characterize the infrastructure of sidewalks, street crossings and public spaces, of the levels of quality of these attributes according the aspect of comfort and safety.

- Weighting of these variables according to their degree of importance for wheelchair users, identified through a survey.

- Definition of an instrument that allows the parameters relating to the technical evaluation and the evaluation of the wheelchair users to be combined into a single quality indicator (index).

Technical evaluation

Sidewalks and public spaces should ensure an appropriate environment that meets the needs of all users with proper conditions of comfort and safety, regardless of their physical limitations, be they permanent or temporary (Fruin, 1987; Khisty, 1994; Sarkar, 1995; Ferreira & Sanches, 2001, 2005; FHWA, 1999, Rakesh, 2007).

Based on these considerations, variables for the physical characterization of sidewalks and urban public spaces were defined, which can be used to describe the aspects of comfort and safety. These variables are related to the movement of people along the block and the movement of crossing street intersections. Table 1 lists the chosen variables and their respective representations that guided the choice.

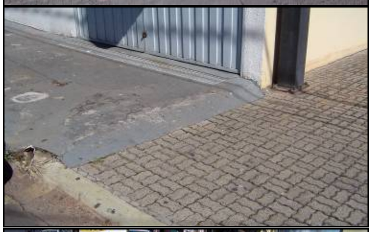
The technical evaluation of the level of quality of the physical infrastructure of public spaces is done by attributing to each of the segments of the analyzed stretch a number of points relative to each variable considered. Technical evaluators should be trained to carry out this work, field evaluations should be done visually and the findings recorded on charts designed especially for this purpose.

The length of each of the analyzed segments should be the same as the face of the property bordering the sidewalk and also the width of the adjacent street, whose sum represents the total length of the evaluated stretch (a block and a street). The analysis should be done individually for each of the segments and the scale should represent the most critical condition of any point or area of the total extent of the segment which is under evaluation.

Table 1. Variables That Characterize the Physical Infrastructure of Public Spaces

Variables	Representation
Longitudinal profile (leveling of the grade)	Variation of the sidewalk profile along the entire block.
Surface of the sidewalk pavement	Condition of the sidewalk surface, expressed in terms of quality of maintenance.
Material used on the sidewalk surface	Suitableness of the types of material used in the construction of the paved sidewalk.
Effective width of the sidewalk	Free width available for circulation of sidewalk users.
Intersection of urban streets	Suitableness of street intersection crossings in terms of equipment, signs and facilities provided.

Table 2. Longitudinal Profile of the Sidewalk Surface (Change of grade level)

Description of the scenario / Scale	Scenario illustration
No unevenness (regular) / Scale = 5	
Unevenness of up to 0.5 cm / Scale = 4	
Unevenness between 0.5 and 1.5 cm, on a 1:2 ramp / Scale = 3	
Unevenness between 1.5 and 5.0 cm in height, with or without concordance (steps) / Scale = 2	
Unevenness between 5.0 and 10.0 cm in height, with or without concordance (steps) / Scale = 1	
Unevenness of more than 10 cm in height, with or without concordance (steps) / Scale = 0	

Tables 2 to 6 show the scale attributed to the possible scenarios as a function of the alterations of each of the variables characterizing the physical infrastructure of the spaces.

Weighting of the attributes (Degree of importance)

An individual's perception is based on his ability to produce information from the environment in which he is inserted, based on psychological stimuli that generate measurable opinions and attitudes. These attitudes are connected to the individual's behavior (experiences and personality) towards the environment, in which he lives, while his opinions refer to his judgment about a given fact, person or object.

To measure the intensity of users' attitudes and opinions objectively, one uses attitude measuring techniques. The Method of Successive Intervals (Guilford, 1975) was chosen for use in this survey because it is a classification technique that is easily applied, which requires the judges (users) to make judgments (evaluations) comparing the series of attributes themselves. The method of successive intervals is used in psychological research when one wants to know the distances between the elements of a scale (interval scales).

Table 3. Surface of the Sidewalk Pavement

Description of the scenario / Scale	Scenario illustration
Excellent conditions, well maintained / Scale = 5	
Good conditions (cracks and other problems are repaired) / Scale = 4	
Regular conditions (small cracks and worn paving material) / Scale = 3	
Precarious conditions (some holes or irregularities with shallow depths) / Scale = 2	
Poor conditions (irregularities and deformations caused by tree roots) / Scale = 1	
Full of holes and loose stones, etc. (impracticable for use) / Scale =0	

Table 4. Materials Used in the Sidewalk Pavement

Description of the scenario / Scale	Scenario illustration
Regular, firm, antiskid and antivibration material (high strength paving) / Scale = 5	
Rough material (hydraulic tiles, interlocked blocks, flattened concrete) / Scale = 4	
Slippery material (smooth ceramic tiles) / Scale = 3	
Paving stones, rustic natural stones, and Portuguese mosaic stones. / Scale = 2	
Flat segmented concrete slabs (separated by grass or other material / Scale = 1	
No pavement or vegetal covering (grass) / Scale = 0	

Data collection

To collect the data required for this survey, interviews were conducted using questionnaires. These interviews involved wheelchair users who are attended by the community medical services provided by the Federal University of São Carlos – UFSCar.

Thus, a group of 45 wheelchair users was invited to participate in this survey and to answer the questions. The questionnaires, which were applied during 2004 by a civil engineering student of UFSCar with an Introduction to Science scholarship, were divided into two parts.

In the first part, the respondents supplied personal information such as gender, age group, level of education, reason for the trip, frequency, and region explored. In the second part, the respondents classified the attributes considered the most important to the characterize the aspects of comfort and safety of sidewalks and street crossings by order of importance, according to a descriptive list supplied in the questionnaire.

The classification was done by attributing a score of 1 to 5, with number 1 representing the highest importance; number 2 the second highest importance, and so on down to number 5, of least importance.

Table 5. Effective Width of the Sidewalk (Free Area for Movement)

Description of the scenario / Scale	Scenario illustration
Free of obstacles. Free area width larger than 2.0 m / Scale = 5	
Free of obstacles. Free width larger than 1.5 m. No street vendors or for other irregular uses / Scale = 4	
Free width larger than 1.5 m at some points. Permits continued movement of wheelchairs / Scale = 3	
Free width area larger than 1.5 m at some points. Requires maneuvers in wheelchair movements / Scale = 2	
Free area width around 0.80 m. Obstructions impair wheelchairs movement. / Scale = 1	
Sidewalk totally obstructed / no sidewalk. Impossible wheelchair movement / Scale = 0	

Table 6. Intersections of Urban Streets – Suitableness of Street Crossings (Safe Crossing)

Description of the scenario / Scale	Scenario illustration
Good intersections with ramps, zebra crossing and traffic lights with exclusive pedestrians time / Scale = 5	
Good intersections with ramps, zebra crossing and traffic lights without exclusive time for pedestrians / Scale = 4	
Intersections with ramps, with zebra crossing and without traffic lights / Scale = 3	
Intersections with ramps, no zebra crossing, no traffic lights, right and left vehicles turns / Scale = 2	
Intersections with no ramps, with zebra crossing and with traffic lights without pedestrians exclusive time / Scale = 1	
Inadequate intersections, without ramps, without zebra crossing and without traffic lights / Scale = 0	

Survey Results

Table 7 lists the general characteristics of the respondents.

Table 8 depicts the results of the survey concerning the importance of the variables characterizing the aspects of comfort and safety of sidewalks and street crossings.

Table 9 shows the weights obtained from statistical procedures applied to the respondents' scores regarding the importance of the variables characterizing the aspects of comfort and safety of sidewalks and street crossings. For the transformation of categorical data to

Table 7. General Characteristics of the Respondents

Age group:	**Degree of Education:**
Up to 15 years – 5% 16 to 30 years – 42% 31 to 45 years – 31% 46 to 60 years – 20% More than 60 years – 2%	Basic – 56% Secondary – 38% College – 6%
Motive of Trip:	**Frequency:**
Work – 47% Study – 63% Shopping – 68% Exercise – 42% Others – 53%	Daily – 64% Several times a week – 31% Sporadic – 5%
Gender:	**Region of circulation:**
Male – 53% Female – 47%	Central Business District – 79% Neighborhoods – 89%

an interval scale the Successive Intervals Method (Guilford, 1975) was used. The rightmost column shows the validation of the sample size (Chi-square test).

Accessibility index of sidewalks and street crossings (routes)

The final evaluation of the environment comprising sidewalks and street crossings can be obtained based on the calculation of an index that measures the quality of accessibility offered to wheelchair users. This index, called the *AI* – Accessibility Index, is calculated from equation 1:

$$AI = \left[\begin{array}{l} 0.24\left(\frac{al_1 l_1 + al_2 l_2 + ... + al_n l_n}{L}\right) + \\ + 0.20\left(\frac{con_1 l_1 + con_2 l_2 + ... + con_n l_n}{L}\right) + \\ + 0.14\left(\frac{mat_1 l_1 + mat_2 l_2 + ... + mat_n l_n}{L}\right) + \\ + 0.16\left(\frac{la_1 l_1 + la_2 l_2 + ... + la_n l_n}{L}\right) + 0.26(ad) \end{array} \right] \quad (1)$$

Where:

- al_i, con_i, mat_i, and la_i: number of points obtained by sidewalk segment *i* in the technical evaluation of the aspects of grade alignment, state of pavement conservation, type of material used, and effective width;
- *ad:* number of points obtained by the street intersection in the technical evaluation;
- l_1, l_2, …, and ln: face lengths of the n properties bordering the sidewalk; and
- *L*: the length of the block = $\Sigma(l_1 + l_2 + \ldots + l_n)$.

Table 8. Importance of the Variables that Characterize Sidewalks and Street Crossings

Variables	Order of importance (num. of answers)				
	1	2	3	4	5
Longitudinal profile (leveling of the grade)	14	15	3	5	8
Surface of the sidewalk paving	8	10	11	9	7
Material used on the sidewalk surface	3	3	13	11	15
Effective width of the sidewalk	5	5	11	14	10
Intersection of urban streets	15	12	7	6	5

Table 9. Weights Attributed to the Characterization Variables

Variables	Weights	Level of precision
Longitudinal profile (leveling of the grade)	0.24	0.99
Surface of the sidewalk paving	0.20	0.97
Material used on the sidewalk surface	0.14	0.87
Effective width of the sidewalk	0.16	0.80
Intersection of urban streets	0.26	0.83

The result of the application of equation 1 represents the evaluation of a complete stretch of sidewalk, considering the total length of one block, plus the width of the street preceding it. Table 10 may be used as a basis for stratifying the AI values into a Level of Service (LS) scale.

APPLICATION OF THE METHODOLOGY

The proposed methodology was applied in the evaluation of a stretch of route comprising three blocks in the central region of the city of São Carlos, SP. São Carlos is a medium-sized city with a population of about 200 thousand.

In order to compare the results with the users perception, a survey was conducted with 10 wheelchair

Table 10. Quality Index and Service Levels (SL)

AI	LS	Condition	Description
= 5.0	A	Excellent	The wheelchair user can circulate unhindered
4.0 ≤ AI< 5.0	B	Very good	The wheelchair user can circulate unhindered
3.0 ≤ AI < 4.0	C	Good	The wheelchair user can circulate with some difficulty
2.0 ≤ AI < 3.0	D	Regular	The wheelchair user needs help to circulate
1.0 ≤ AI < 2.0	E	Poor	The wheelchair user depends on help and must maneuver to circulate
AI < 1.0	F	Awful	Impossible for wheelchair users to circulate

Table 11. Results of the Evaluation

Variables	Blocks					
	1RS	1LS	2RS	2LS	3RS	3LS
Longitudinal profile	4.00	2.26	4.00	3.45	4.00	4.00
Surface of the paving	1.00	1.00	1.00	3.25	2.43	3.00
Material used on the paving	2.00	2.25	2.00	2.30	2.00	4.00
Effective width of the sidewalk	3.00	4.00	3.00	3.65	4.00	5.00
Intersection of urban streets	0.00	0.00	0.00	0.00	1.00	1.00
Accessibility Index / Service Level	1.92 / D	1.70 / E	1.92 / D	2.38 / D	2.63 / D	3.18 / C
User evaluation / Service Level	1.50 / E	1.50 / E	2.00 / D	2.50 / D	2.50 / D	3.00 / C

Note: RS = right side, LS = left side.

users. They moved along the same stretches of streets analyzed by the technical evaluators and attributed to each segment a score from 0 to 5. Table 11 shows the results obtained. The values in the last row correspond to the average score attributed by the users.

It is possible to verify that, even though the final values are not very different, the wheelchair users were more rigorous in their evaluation and one of the segments attained a lower level of service.

CONCLUSIONS

The study presented in this paper is part of a broader research proposal aimed at developing a model, based on behavioral studies and technical surveys of infrastructural conditions, to evaluate the degree of accessibility for wheelchair users during their movements through public spaces in city street networks.

The results obtained from the initial studies presented herein allow us to draw the following conclusions:

1. The users' perceptions concerning the importance of the attributes characterizing the infrastructure of sidewalks and street crossings should be taken into account, since they allow one to establish an order of priority of the variables defining the aspects of comfort and safety.
2. The technical evaluation proved efficient and easily applicable to identify the current infrastructural conditions of sidewalks and street crossings, as well as their design characteristics (conception).
3. The accessibility index (AI) which considers the current conditions and design characteristics of the infrastructure of sidewalks and street crossings, weighted according to the relative importance of each of the attributes from the respondents' point of view, provides a classification of the analyzed stretch in terms of levels of quality of the services offered.
4. The case study conducted in the city of São Carlos, state of São Paulo, Brazil, revealed the poor accessibility of the stretch of sidewalks and street crossings analyzed, which was found to be unsuitable for use as a route for wheelchair users. The scenarios selected to represent the variables characterizing the infrastructure of sidewalks and street crossings are typical of the majority of Brazilian cities.
5. The proposed methodology can be used by public authorities or managers of urban services to evaluate the quality of accessibility to urban infrastructure and to identify locations that require physical interventions, as well as the types of interventions to be implemented to improve the accessibility. The weights attributed to the variables should be determined empirically, by surveys, for the application of the method to other cities.

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