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Walkability in modern cities: A methodological framework for the analysis and evaluation of pedestrian networks of neighborhoods

Abstract

In recent years, car usage in modern cities has greatly increased and emphasis is given on road network planning, thus downgrading usage of all alternative means of transport. However, at the same time, the terms sustainable development and sustainable mobility have been introduced to urban planning, mainly to solve problems that have emerged from the consequences of car usage and to improve residents' quality of life (QoL). Sustainable mobility promotes alternative means of transport and especially walking, which improves quality of life and health conditions of residents, both physically and mentally, and is measured with the help of walkability indices. The term walkability indicates the degree to which an area is attractive, friendly and suitable for pedestrian movement and, as a result, for each of the elements of the pedestrian network of a neighborhood a Walkway Performance Indicator (WPI) is created by the evaluation of both infrastructure and land use variables. For the evaluation of each neighborhood's pedestrian network, a focal point is used, which in this case is a school unit, in order to determine neighborhood central areas, that should be as good or better than other neighborhood areas, so that they offer better safety conditions for neighborhood residents and especially children. With the help of Geographical Information Systems (GIS), it is possible to determine which areas in a specific neighborhood offer better walkability and QoL conditions, by determining clusters of high or low WPI values and outliers combining the two categories. As a result of this spatial analysis and the performance assessment of neighborhood centers, coverage percentages of clusters and outliers emerge for central and other areas of neighborhoods, thus resulting in more useful conclusions about each neighborhood's strengths and weaknesses and where those are located.

Keywords: Performance assessment, Quality of life, Sustainability, Neighborhoods, G.I.S.

1. Introduction

Modern cities constantly change in a dynamic way, while adapting with the technological advancement of each era. Technological improvements affect residents' everyday life and, as a result, city structure and its functionality, while this change is based on residents' wants and needs, which mostly concern housing, work, recreation and especially mobility issues (Aravantinos 2007). However, even when in the history of cities urban environment transformation is apparent on more complex structures, walking is still considered the main means of transport. City distinction takes place in three categories, concerning transport systems of each historical time and is based on the fact that residents do not choose to travel towards central locations if they are located more than half an hour away, regardless of the transport means (Newman et al. 1996). These three categories consist of cities for walking, cities of mass means of transport and “car cities”, while most modern cities are featured as car cities. It is clear that different city forms affect walkability (Frank et al. 2010) and that with the passing of time and technology development, car usage is favored, which in turn has a negative effect on alternative means of transport, such as walking, biking and mass means of transport. As a result, sustainable development and satisfactory quality of life conditions in modern cities, where car usage is higher, tend to be more difficult to achieve.

In order to achieve sustainability, the New Urbanism movement has emerged, which promotes principles of sustainable community planning, while focusing on effective ways of spatial organization of transport networks. Also, all ways of transport are directly correlated with urban planning and in this case Smart Growth is involved, which is a theory of urban and transport planning that focuses on the development of compact and walkable city centers, which results in the avoiding of urban diffusion with the help of specific ways (Heaton – Kennedy & Dannenberg 2012). Most notable ways of achieving this are the creation of walkable neighborhoods, land use mixture, the preservation of public and green spaces and also the accessibility concerning means of transport and the increase on pedestrian and bicycle infrastructure (Steiner 2012). In addition, walking benefits not only the residents of a city but the city itself, as it is considered as a global means of moving around, offering not only mobility but recreation and exercise as well, while improving how a city looks and its residents’ health (Litman 2011).

Improving a city’s looks and overall resident health can only improve living conditions and quality of life in general. City residents are a priority of human development on improving quality of life (Miles 1985), where freedom, health, education, safety, economic development and overall resource accessibility are considered its key elements. As a result, quality of life in a specific community can be affected by the overall plenitude of available resources, which can be separated in the categories of land use, infrastructure and mobility, where, in the case of walkability, mobility is considered the most important factor. Residents’ overall satisfaction can be achieved through a number of ways, which concern social, economic and physical elements of a neighborhood (Dahmann 1981; Sirgy, Cornwell 2002) and, as a result, in this article such elements are examined, with walkability being a priority, in order to assess each neighborhood’s pedestrian network performance.

2. Methodology

This process consists of an approach to determine remarkable areas of neighborhoods which show high, low or a combination of Walkway Performance Indicator (*WPI*) values and, therefore, conclusions can be drawn about which subareas, within a neighborhood, perform better or worse for a certain category.

2.1. Walkway Performance Indicators (*WPI*)

In order to better determine each neighborhood’s best parts, each part of its pedestrian network (each walkway) must be examined, firstly from the aspect of its infrastructure, where walkway elements such as pavement width, overall state and bike lane existence are examined, as well as infrastructure for people with disabilities, existence of pedestrian crossings, absence of obstacles and adequacy of means of public transport. Apart from infrastructure factors, land use elements are also examined which consist of housing, public or open spaces, commercial uses and public or private services.

In order to evaluate its pedestrian walkway's performance, overall plenitude of each walkway is examined, instead of total plenitude of a neighborhood. In order to sort out which elements belong to each walkway, spatial proximity analysis is applied, as shown on Image 2.1.

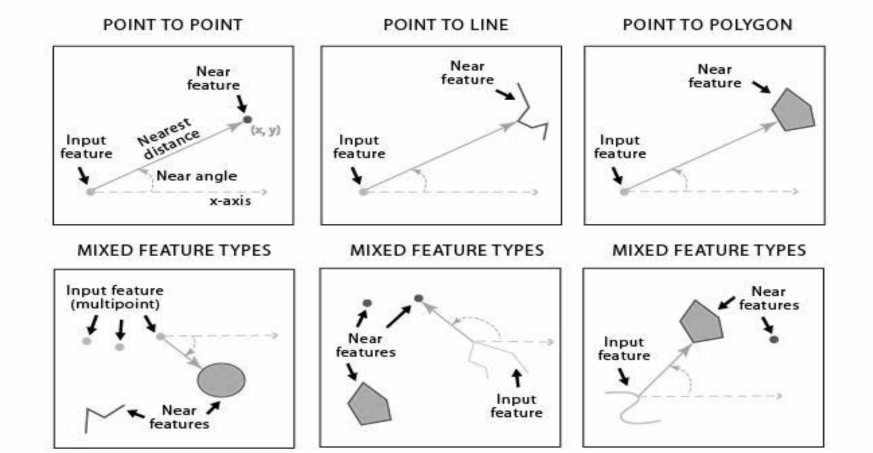

Image 2.1. Spatial proximity analysis ("Near" tool). Source: http://pro.arcgis.com/en/pro-app/tool-reference/analysis/near.htm

With the help of the above tool, each land use or infrastructure element belongs to its nearest walkway element, which results in the analysis of each walkway separately, in order to determine their overall performance indicators. Using the values of each part of a pavement (walkway), it is possible to examine where and how a neighborhood performs, with the help of spatial autocorrelation and the use of Moran's I indices (Global Moran's I and Anselin Local Moran's I). Specifically, when a spatial pattern is not random, whether it is clustered or dispersed, the Local Moran's I index determines where and what kind of clusters or outliers of values appear in a specific area (Anselin 1995). The result of this analysis is a thematic map where every spatial entity is classified into five categories:

- **High – High clusters**: spatial entities of high values that overlap with entities of also high values
- **High – Low outliers**: spatial entities of high values that overlap with entities of low values
- **Low – High outliers**: spatial entities of low values that overlap with entities of high values
- **Low – Low clusters**: spatial entities of low values that overlap with entities of also low values
- **Non-Significant**: spatial entities that do not show a statistical significance of Local Moran's I index

For the analysis of every spatial entity, its WPI must be calculated, following the methodological framework shown on Table 2.1.

Table 2.1. Methodological framework for the calculation of WPIs

	Infrastructure	**Land use**
Densities	$d_{var} = \frac{\sum_i^n var}{length}$	
Notable calculations	$crosswalk_{min} = \frac{1}{length_{max}}$ $crosswalk_{score} = \frac{density}{crosswalk_{min}}$	
Weight correlation	$score'_{var} = w_{var} \cdot score_{var}$	
Category score	$score_{category} = \sum_i^n score'_{var}$	
Normalization	$score_{norm} = 1 - \frac{(score_{category} - max_{\Sigma var})}{(min_{\Sigma var} - max_{\Sigma var})}$	
Walkway Performance Indicators (WPIs)	$score_{sum} = \sum_i^n score_{category}\, , WPI = 1 - \frac{(score_{sum} - max_{\Sigma var})}{(min_{\Sigma var} - max_{\Sigma var})}$	

In order to correlate every variable and sub-variable with its corresponding significance, the significance values (weights) shown on Figure 2.1 and Table 2.2 were used, as generated by a questionnaire survey.

Figure 2.1: Variable significance

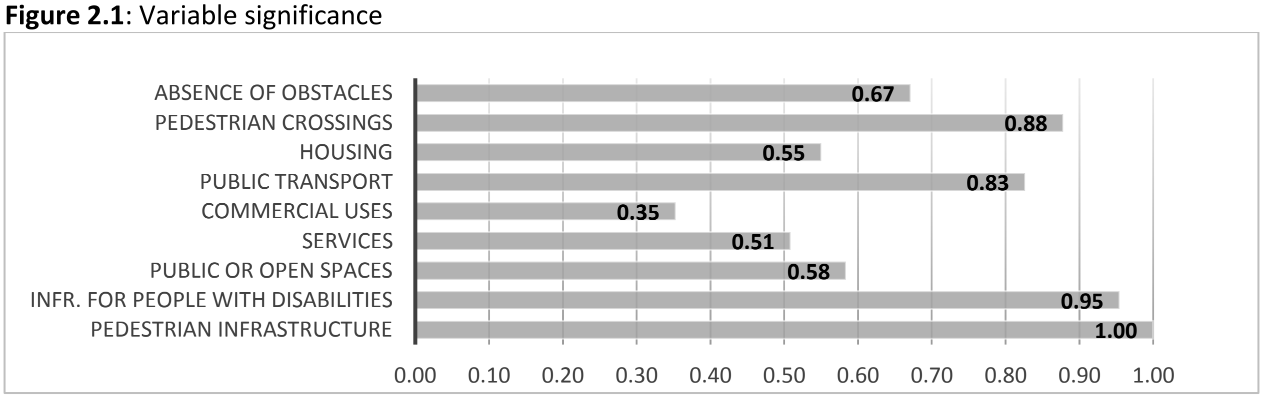

Table 2.2. Sub-variable significance

Variables	Sub-variable	Significance
Pedestrian infrastructure	Sidewalk status	1
	Sidewalk width	0,876
	Existence of bike lane	0,871

As shown on the above results, pedestrian infrastructure is considered the most significant variable and infrastructure for people with disabilities is almost as much significant.

2.2. Neighborhood Center Performance Analysis

Because of this, the Neighborhood Center Performance Indicator (NPI_{center}) is created, which is a correlation index that examines the relationship of pedestrian network performance at the center of a neighborhood with pedestrian network performance of all the rest areas of the specific neighborhood, in order to determine if a center is considered inferior or better than the rest of the neighborhood.

As for the analysis concerning the center of every neighborhood, it is not defined randomly, as it is a site of particular importance that functions primarily as a meeting place for neighborhood residents and can, in addition to a school unit, be any place of equal importance. Therefore, even if a neighborhood is considered "good", if its center is not at least as good, then that neighborhood cannot be described as fully viable, nor does it provide the best quality of life conditions. In the process of analyzing walkway parts of each neighborhood, the neighborhood center performance indicator is calculated, according to the relation:

$$NPI_{center} = \frac{WPI\ average\ at\ neighborhood\ center}{WPI\ average\ at\ areas\ outside\ neighborhood\ center}$$

where NPI_{center} is the neighborhood's center performance indicator, compared to the rest of the neighborhood.

As mentioned above, this specific process results in the production of different performance indicators for every single walkway of each neighborhood's pedestrian network. By calculating WPIs for every walkway, it is possible to determine which areas show strengths or weaknesses concerning specific categories or overall, which leads to the final assessment of where a neighborhood performs better and especially if its central areas perform better or worse than its other areas.

3. Results

Results from neighborhoods that did not show a random spatial pattern and where examined with the help of Anselin Local Moran's I index are shown on the following tables. For every neighborhood, coverage percentages are generated about all four categories of clusters (High – High or Low – Low areas) and outliers (High – Low or Low – High areas), areas outside the center of each neighborhood (Table 3.1) and neighborhoods' central areas (Table 3.2).

Table 3.1: Overall WPI area coverage outside neighborhood centers

Neighborhoods	High - High	High - Low	Low - High	Low – Low
106th Athens Primary School	0.00%	0.00%	3.25%	0.00%
142th Athens Primary School	0.60%	0.11%	0.00%	8.90%
16th Athens Secondary School	0.00%	0.00%	6.78%	0.00%
1st & 19th Zografou Primary Schools	5.14%	0.00%	2.72%	**27.41%**
1st Agios Dimitrios High School	0.00%	0.00%	0.24%	11.63%
1st Ilion Primary School	0.00%	0.00%	0.00%	0.00%
1st Neo Psichiko Primary School	1.61%	0.00%	0.00%	8.81%
1st Halandri Primary School	0.00%	0.00%	0.00%	9.99%
1st - 5th - 7th Athens Primary Schools	0.00%	4.44%	0.00%	7.71%

2nd Halandri Secondary School	0.00%	0.00%	0.00%	5.22%
2nd Athens Primary School	3.02%	0.00%	0.00%	3.42%
4th Halandri High School	4.67%	0.00%	0.66%	9.35%
4th Zografou High School	4.49%	0.00%	0.00%	2.53%
57th Athens Secondary School	0.00%	0.00%	0.00%	**15.87%**
5th Zografou Primary School	14.36%	0.00%	0.00%	0.82%
5th Athens High School	7.95%	0.00%	3.44%	4.33%
77th Athens Primary School	3.53%	0.00%	3.65%	14.73%

Table 3.2: Overall WPI area coverage at neighborhood centers

Neighborhoods	High - High	High - Low	Low - High	Low – Low
106th Athens Primary School	0.00%	0.00%	0.00%	**70.86%**
142th Athens Primary School	0.00%	0.00%	0.00%	13.37%
16th Athens Secondary School	0.00%	0.00%	0.00%	**23.75%**
1st & 19th Zografou Primary Schools	14.27%	0.00%	31.65%	0.00%
1st Agios Dimitrios High School	0.00%	0.00%	0.00%	0.00%
1st Ilion Primary School	**16.71%**	0.00%	9.62%	0.00%
1st Neo Psichiko Primary School	0.00%	0.00%	0.00%	**27.01%**
1st Halandri Primary School	0.00%	0.00%	0.00%	0.00%
1st - 5th - 7th Athens Primary Schools	0.00%	0.00%	0.00%	0.00%
2nd Halandri Secondary School	0.00%	0.00%	0.00%	**23.08%**
2nd Athens Primary School	0.00%	0.00%	0.00%	0.00%
4th Halandri High School	0.95%	2.91%	0.00%	0.00%
4th Zografou High School	0.00%	0.00%	0.00%	**31.04%**
57th Athens Secondary School	0.00%	0.00%	0.00%	**17.54%**
5th Zografou Primary School	**16.50%**	0.00%	8.47%	0.00%
5th Athens High School	0.00%	0.00%	0.00%	**46.97%**
77th Athens Primary School	0.00%	0.00%	0.00%	**51.06%**

Regarding the overall performance indicators concerning pedestrian network, several useful conclusions can be drawn. Neighborhoods with high coverage of low values of overall *WPI* (low – low area coverage above 15%) are in red, whereas areas of high coverage of high values of overall *WPI* (high – high area coverage above 15%) are in green. These results show which neighborhoods tend to have high or low *WPI* values at their central or other areas, while it is clear that there are many cases of neighborhoods which show very high coverage of low values at their centers, as shown on Table 3.2.

Table 3.3: Neighborhood Center Performance Indicator (NPI_{center}) and overall NPI

Neighborhoods	*Overall WPI average at center*	*Overall WPI average outside center*	*Overall NPI (%)*	NPI_{center}
106th Athens Primary School	1,012	1,539	36,48	**0,658**
11th Halandri Primary School	1,462	1,376	28,08	1,062
13th – 16th Zografou Nursery Schools	1,334	1,419	26,34	0,941
142th Athens Primary School	1,674	1,668	36,98	1,004
16th Athens Secondary School	1,402	1,351	29,91	1,038
1st – 19th Zografou Primary Schools	1,579	1,445	23,88	1,092
1st & 2nd Zografou Secondary Schools	1,573	1,433	24,00	1,098
1st – 3rd Holargos Secondary Schools	1,500	1,377	24,68	1,089
1st Agios Dimitrios High School	1,760	1,536	35,94	**1,146**

1st Ilion Primary School	1,942	1,806	52,46	1,075
1st Neo Psichiko Primary School	1,295	1,381	15,80	0,938
1st Halandri Primary School	1,568	1,348	21,53	**1,163**
1st - 5th - 7th Athens Primary Schools	1,581	1,608	49,51	0,983
2nd Halandri Secondary School	1,538	1,591	23,62	0,966
2nd Athens Primary School	1,727	1,783	60,05	0,968
2nd Metamorfosi Primary School	1,517	1,337	26,94	**1,135**
3rd Agioi Anargiroi High School	1,387	1,443	31,79	0,961
3rd Vrilissia Primary School	1,701	1,532	39,58	**1,110**
49th Athens Secondary School	1,452	1,406	27,97	1,033
4th Halandri High School	1,639	1,490	29,82	**1,100**
4th Argiroupoli Secondary School	1,851	1,849	47,41	1,001
4th Zografou High School	1,416	1,591	42,66	**0,890**
56th Athens Secondary School	1,819	1,781	43,15	1,021
57th Athens Secondary School	1,472	1,320	30,56	**1,115**
5th Zografou Primary School	1,478	1,426	34,10	1,036
5th Athens High School	1,133	1,623	41,69	**0,698**
6th Athens Vocational High School	1,715	1,806	44,91	0,949
6th Nursery – 5th Secondary Nea Ionia Schools	1,856	1,752	37,87	1,059
77th Athens Primary School	1,431	1,424	32,92	1,005
7th Athens High School	1,765	1,810	43,68	0,976
8th Agios Dimitrios Primary School	1,568	1,484	34,74	1,057
Special Primary School of Pedagogical Section of University of Athens	1,566	1,602	34,23	0,977

In order to better understand these results, on Table 3.3, overall *WPI* averages at central and non-central areas are calculated (on an absolute form, rather than a percentage one) and then compared with the overall *NPI* of each neighborhood, to better determine if a "good" neighborhood shows an inferior or better center, compared to its other areas. In this case, neighborhood centers are classified in three categories:

- $0 \leq NPI_{center} < 0.90$: neighborhood center worse than the rest of the neighborhood
- $0.90 \leq NPI_{center} \leq 1.10$: neighborhood center as good as the rest of the neighborhood
- $1.10 < NPI_{center}$: neighborhood center better than the rest of the neighborhood

Notable neighborhoods which show high overall *NPI* percentages but also show low NPI_{center} values are those of the 106th Athens Primary School and the 5th Athens High School, which show *NPIs* of over 35%, but NPI_{center} values of less than 0,7. On the other hand, there are some neighborhoods which show NPI_{center} values higher than 1.10, however these values tend to be close to the 1.10 mark, which means that even though they show better centers than their other areas, they do not stand out as much as the previous two cases.

Consequently, through the examination of the above results, it becomes clear that there are neighborhoods where more importance has been given to different subareas and not on their central areas. These areas are the most important ones as they contain the school units as focal points, which operate as meeting points for a neighborhood's residents and, as a result, must be given more attention during the planning and conservation processes of a neighborhood.

4. Discussion and Conclusions

From the pedestrian networks analysis of the examined neighborhoods, useful conclusions can be drawn. As shown on the above results, there are many cases where a neighborhood's overall performance contradicts with the results from the analysis of neighborhood centers. In other words, even if a neighborhood is initially considered "good" or "bad", this does not necessarily mean that its central areas are also "good" or "bad" respectively. This analysis is of paramount importance because of the importance of the focal point of each neighborhood, which in this case is a school unit and, as a result, must meet all safety conditions as it is considered a meeting point for a neighborhood's residents.

As shown above, nine out of thirty-two neighborhoods (28.1% of the overall sample) deviate from their initial results. While analyzing the results of both NPI_{center} values and overall *WPI* coverage, especially at neighborhood centers, it is made clear that there are many cases which show that even if a neighborhood performs high enough to be considered "good" overall, its primary focus is not the central and most important area, which is the meeting point of its residents. Consequently, neighborhoods with underperforming centers cannot be eventually considered ideal, which creates the need for further improvement of neighborhoods, especially at their central areas. In order to improve safety conditions at the focal points of each urban neighborhood, the following suggestions are made:

- Creating more walkways, while upgrading already existing sidewalks, by increasing total pedestrian zone width and creating better infrastructure for people with disabilities;
- Limiting total roads cutting through the neighborhood center and limiting their total width which results in limiting car usage;
- Increasing and upgrading already existing bike lanes, in order to promote the specific alternate means of transport, especially for school students, parents and elders;
- Creating more parks and other green spaces, in order to increase meeting points for the neighborhood's residents, while promoting sustainability through various environmental actions;
- Creating better lighting adequacy conditions in the center of the neighborhood;
- Improving land use mixture, with the existence of shops, open spaces, parks and more housing opportunities which eventually create new job opportunities, promote social interactions and create a greater sense of security for the neighborhood's residents.

In conclusion, findings of this article show the importance of neighborhood centers in promoting sustainability, better quality of life (QoL) conditions and especially residents' safety. Neighborhood centers are of great importance in the specific approach, as they operate as meeting points for all neighborhood residents, of all age groups and social status, which results in the creation of more safety conditions. By improving the feeling of safety, QoL conditions are also directly improved, as security is the primary factor in perceiving one's quality of life. Summarizing, neighborhood pedestrian network and center analysis are of great importance to any future attempt of neighborhood performance and QoL assessment.

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