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Developing a Walkability Index for Built Environment and its Applications at Different Spatial Levels

Emad Dawwas[1,*] & Ayah Helal[1]

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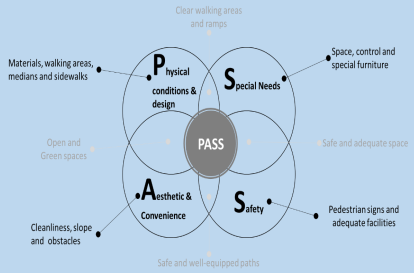
Abstract: Walking is being widely recommended by the mainstream research about sustainable development as a preferable commuting mode for health, economic and environmental reasons. Therefore, designing and implementing walkable communities are increasingly becoming main goals adopted by urban planners and transportation engineers. Considering a wide range of walkability parameters, this study aimed to develop a quantification method of walkability based on the technical standardization. The study proposed a multi-component walkability index “PASS” that stands for the four measurable components of the index including: Physical design component (P); Aesthetic and convenience component (A); Safety component (S) and Special needs requirements (S). The PASS index was constructed using field data that was collected about 1418 road segments with overall length of 253.1 km in Nablus city, West Bank, Palestine. The value of the index ranges from 0 (the worst walking conditions) to 5 (the best conditions). A special Geographic Information Systems (GIS) tool was designed to accommodate the PASS index and to represent the results spatially. PASS was found to be an effective tool in quantifying and assessing walkability at four spatial levels: (1) road and road segment level; (2) road network level; (3) neighborhood and district level; and (4) city level. Therefore, decision-makers, planners, and engineers can benefit from the proposed methodology to identify where interventions are required and to prioritize budget allocation to improve the walking environment at all spatial levels. The proposed tool is a significant methodological contribution to the field of urban and city planning as it can be easily replicated in other cities with limited financial and technical resources.



Keywords: Sustainability, Inclusive city, Walkability index, Walkable communities.

Introduction

Improving walkability in urban areas is a high priority for urban planners and decision-makers due to the substantial benefits associated with walking for the individuals and the communities. The mainstream literature about sustainable development and liveable communities recommends walking as a top-ranked active transportation mode and the most favorable healthy one (1). Urban planners and transportation engineers promote walkability as an essential principle of transit-oriented development (TOD) to limit the urban sprawl for the sake of reducing Vehicle Miles Traveled (VMT) and greenhouse gas emissions (2, 3). Public health specialists perceive walkability as a solution for obesity and chronic diseases (4; 5; 6; 7). Researchers in the aforementioned fields have recently worked in specialized teams and multidisciplinary groups on measuring and evaluating walkability as a first and essential step toward a walkable built environment (3; 8).

Furthermore, there is a growing evidence in the literature showing that people tend to walk more in highly walkable areas. Consequently, improving the built environment will most likely enhance people’s perception towards walkability. The Environmental Protection Agency (EPA), for instance, developed a walkability index consisting of three physical indicators: design, availability of transit and land uses in the area (9). Watson et al 2020 found that the EPA index was strongly associated with a higher likelihood of walking. More studies have reached the same results, indicating a positive association between walking and the quality of the built environment in the United States (10), in Europe (11), and in developing countries (12; 13).

As shown above, there are global interests in measuring and evaluating walkability at different spatial levels and from different perspectives. Most of these attempts took place in Western and developed countries (14; 15; 16; 17) and a few of them in developing countries (12; 13).

This study is conducted in a developing country, namely Palestine, where limited data and budget is available. The main objectives of this study are to: (1) Develop a walkability index using physical characteristics of the built environment following a new methodology that suits the limited resources and data contexts; (2) Design and implement a GIS tool that can be easily established and used by other researchers to calculate the suggested walkability index and measure the level of walkability; and (3) Employ the proposed index on a real-world application in order to show the extent to which the proposed methodology and GIS tool can be used to quantifying the walkability.

The methodology and the proposed walkability index contribute significantly to the field of urban planning, urban design, and transportation planning, in general, and in measuring and evaluating walkability in developing and poor countries, in specific.

Conceptual Model

Measuring walkability by a single index is a challenging endeavor because no one quantity exists to measure walkability in the literature. Some studies focus on how easily pedestrians can walk from one place to another as the basis of walkability quality (13; 18). Other studies consider aesthetic aspects of street components, the convenient places to walk to, and the convenience of the walking environment within and around the

1 Department of Planning and City Technologies, Faculty of Engineering and Information Technology, An-Najah National University P. O. Box 7, Nablus, Palestine
*Corresponding author: dawwas@najah.edu

street network (19; 20). Pedestrian safety while walking is another factor that has been wildly considered as a component of walkability (21). Other features are considered for particular purposes like suitability of routes conditions, sidewalks, surface conditions, slope for wheelchair rolling, and special needs (22; 23).

Referring to the previous studies, walkability can be conceptualized as a measure of four components including:

(1) Physical and Design (P): Physical design should consider the accessibility and connectivity to nearby destinations with small blocks and gentle slopes. The design should assure enough space so that users can walk in their own space without being blocked or pushed around.

(2) Aesthetic and Convenience (A): The walking environment should be clean, comfortable, and aesthetically pleasing where people can enjoy their time. The walking environment should also be convenient for pedestrians while moving from one point to another. Available spaces should foster a sense of place and provide aesthetic scenes.

(3) Safety (S): In order to achieve the safety principle, pedestrians should not be subjected to danger or side friction with motorized traffic. There should be safe public spaces and pedestrian networks should allow secure access for all people. There should be adequate signage for pedestrians and signage for drivers to alert them to give priority to pedestrians.

(4) Special needs requirements (S): Pedestrian facilities and available spaces should be designed to accommodate mobility-impaired users including wheelchair users, the visually impaired, baby strollers, pregnant women, and the elderly. More importantly, paths for the mobility impaired users should be, where possible, integrated with the main network to avoid further detours.

The four components can be abbreviated to PASS as shown in the conceptual diagram in Figure (1) below. PASS, the proposed walkability index, will measure the extent to which the built environment encourages people to incorporate walking into their daily journeys, enjoy their walking, feel safe, and the extent to which it accommodates mobility-impaired users.

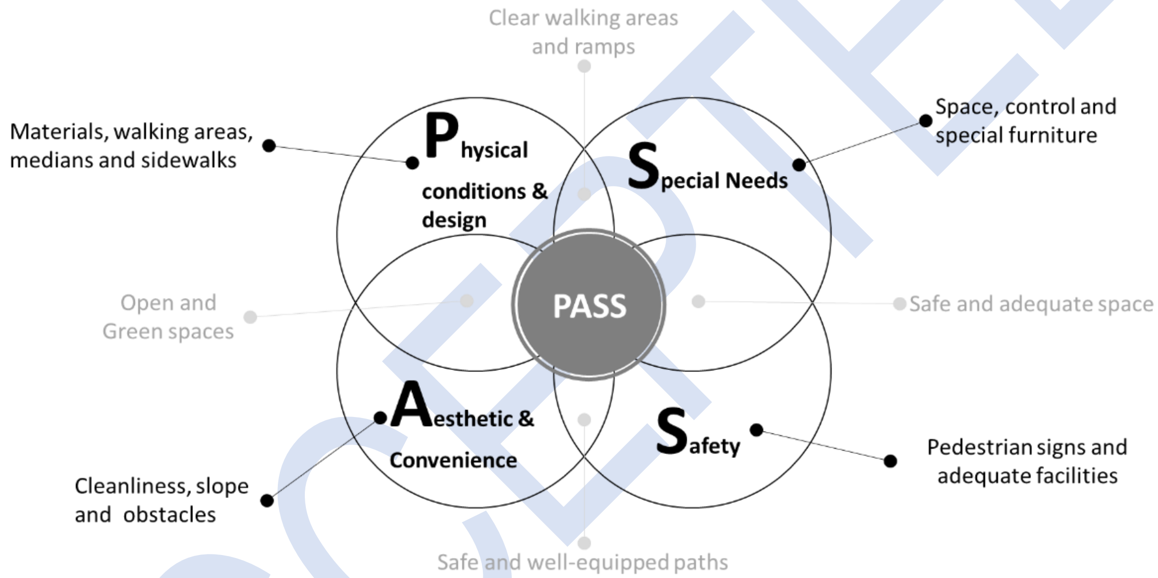


Figure 1. Conceptual Model of Walkability The paper follows a multicomponent approach to develop and test the proposed PASS walkability index as discussed in detail in the following section.

Materials and Methods

The walkability index PASS proposed in this research is a comprehensive one including a representative number of factors that have been considered in the literature. More importantly, all factors of the index can be practically measured with least cost and least effort. Referring to the conceptual model shown in Figure (1) above, the researchers defined a set of 52 indicators as a first step. In the next step, the data about each indicator was collected from the field using a field survey designed specifically for this purpose.

The indicators are classified into four categories as shown in Figure (2) below and defined as follows:

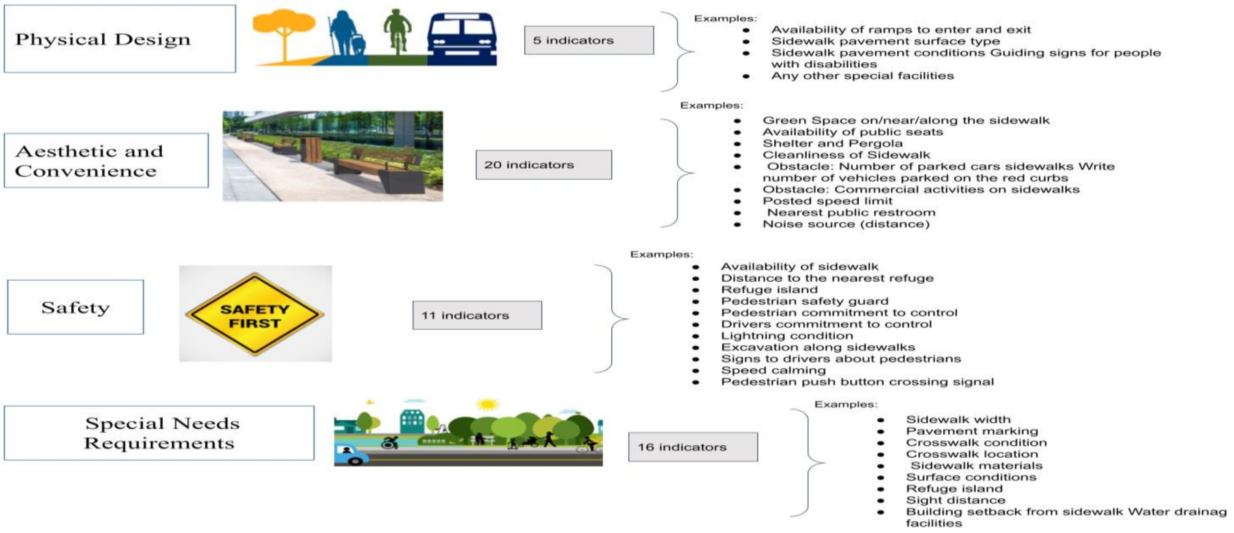


Figure 2. Classes of walkability indicators

(1) Physical conditions and design (P) indicators: this category consists of 5 indicators and includes all basic components of the street furniture that have no function but to be used by pedestrians.

(2) Aesthetic and Convenience (A) indicators: this category consists of 20 indicators and includes all features that make the physical environment more (or less) appealing as well as the features that make the walking environment more (or less) comfortable and make the built environment more (or less) attractive for pedestrians.

(3) Safety (S) indicators: this category consists of 11 indicators including the features that participate in creating a safer (or unsafe) environment for pedestrians to walk from one point to another, to cross streets, to refuge while crossing, to eliminate conflict points with traffic…etc.

(4) Special Needs Requirements (S) indicators: this group of indicators includes 16 indicators. The indicators are mainly focused on the street features and design criteria that produce a welcoming environment for handicapped people and mobility impaired users.

Nablus city, a major city in the West Bank – Palestine, was selected to collect data, develop and testing the PASS index. Nablus city is a national commercial center with 29.83 Km2 area and a population of 174.4 thousand people (24). The total length of the roads within the master plan is (about 361 km excluding the local residential streets). The study covers 253.1 km which constitutes about 70% of the road network in Nablus city.

Each one of the 52 indicators was evaluated on a scale of 5 such that an indicator takes 0 in the worst conditions and 5 in the best ones. There are two exceptions in this scoring system; in the first exception, four indicators were given a zero score if not available and a score of five if available. This group of indicators includes the availability of: drinking fountains, public restrooms, speed limit sign and speed calming measures. In the second exception, the availability of aggressive dogs' indicator is given zero if it is available and five if not. A sample of scoring indicators is listed in Table (1) below.

Table 1. Sample of the Criteria and their Scoring System

Scores Criteria	0	1	2	3	4	5
Availability of sidewalk	Does not exist	covers up to 25%	25–50%	50 – 75%	75 – less 100%	100%
Distance to the nearest refuge island	No refuge island or d > 12 m	10-12m	8-10m	6-8m	4-6m	d < 4 m
Refuge island width	Does not exist	less than 1m	1-2m	2-3m	3-4m	Width > 5m
Availability of drinking fountain	Does not exist	---	---	---	---	Exists
Availability of aggressive dogs	Exist	---	---	---	---	Does not exist

All calculations were done at the road segment level that is defined as the midblock between two consecutive intersections regardless of the length of the midblock. The final index will be used to evaluate each road segment and then it can be aggregated to upper spatial levels including: street level, street network level, neighborhood/district level, and city level.

The generated PASS index is a function of the four index components: $P_{hysical}$, $A_{esthetic}$, S_{afety}, and $S_{pecial\ needs}$. For each road segment, the PASS value was calculated as an average of the four component values according to Equation (1).

$PASS_{index} = (P_{hysical} + A_{esthetic} + S_{afety} + S_{pecial\ needs})/4$ …. Eq. (1)

When calculating the index, the four components are given the same weight indicating equal importance for the planners and engineers. Each component is calculated at the road segment level as the average of all indicators in the same component according to the equations from 2 to 5 below.

$P_{hysical} = \sum_{i=1}^{n=5} P_i \text{ score}/ N_P$ …………………………….. Eq. (2)

$A_{esthetic} = \sum_{i=1}^{n=20} A_i \text{ score}/ N_A$ ………………………….. Eq. (3)

$S_{afety} = \sum_{i=1}^{n=11} S_i$ score/ N_{SF} …………………………….. Eq. (4)

$S_{pecial\ needs} = \sum_{i=1}^{n=16} S_i / N_{SP}$ …………………………….. Eq. (5)

N: number of indicators in each component.

A GIS tool was specially designed for the purpose of walkability analysis and mapping. The tool is a GIS model implemented within ESRI ArcGIS 10.1 environment as shown in Figure (3). The inputs are the four sets of indicators illustrated in Figure (2) above and the output is the walkability index presented at five spatial levels that will be discussed in detail in the following section.

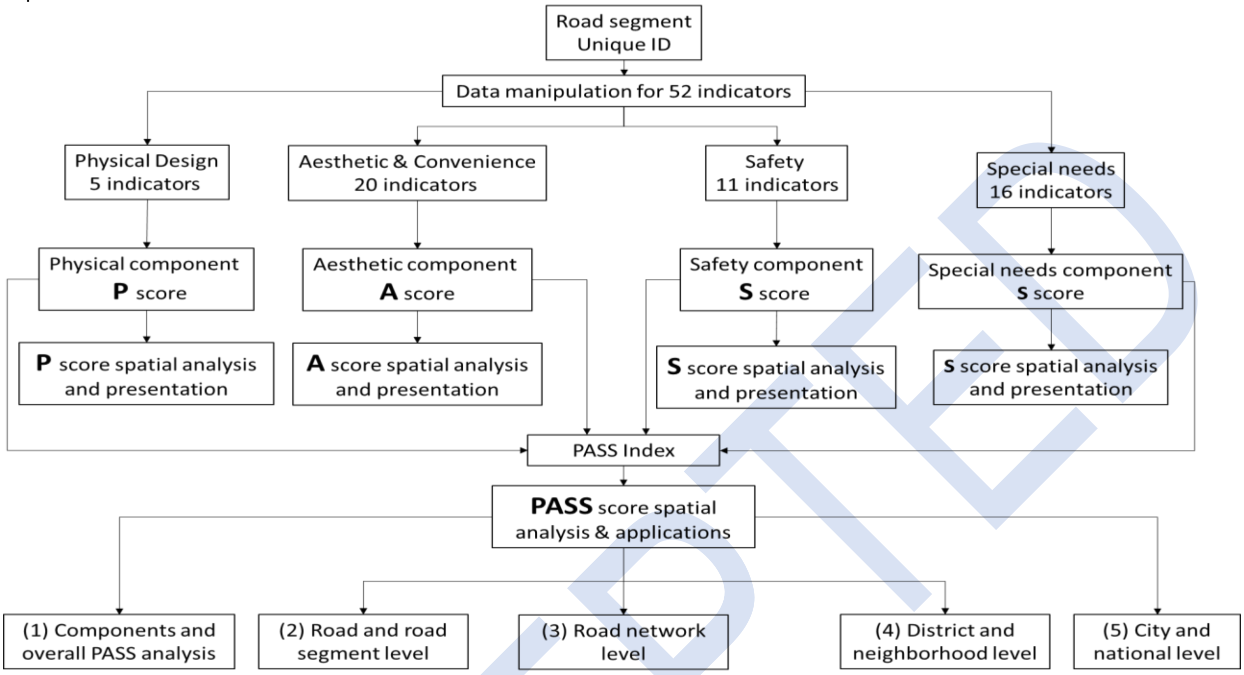


Figure 3. Data manipulation and PASS index generation methodology within GIS environment

Each road segment on each side of the road (the left side is a segment and the right side is another segment) between two consecutive intersections was given a unique ID and surveyed by a separate data collection sheet. Each component of the four walkability components is added as a new attribute to the road segment. All scores of indicators were standardized on a scale of 0 to 5 such that the worst score is 0 and the best score is 5.

The generated index can be further used in the spatial analysis at the street segment level. The results can be aggregated to higher spatial levels such as roads, neighborhood or district, and at city level. The total number of road segments shown in Figure (4) and Table (2) is 1418 segments out of which are 137 classified as arterial, 174 collectors, and 1107 local with overall length of 253.1 km.

Table 2. Number and length of roads on two-directional basis

Road type	Count of road segments	Total length of each type in meter
Arterial	136	23,884.6
Collector	174	32,896
Local	1108	196,314
Total	1418	253094.6

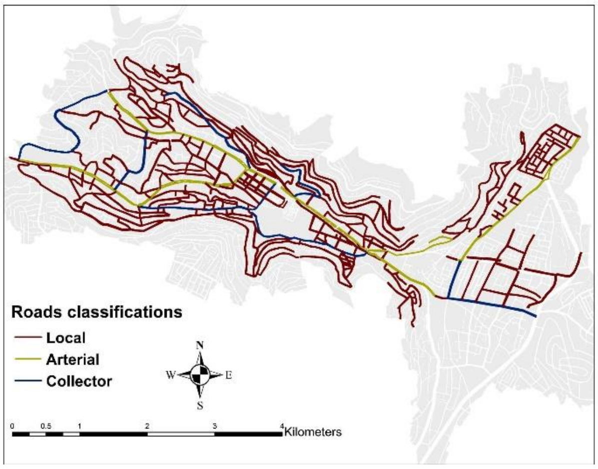


Figure 4. Functional road classification in the study area

The GIS model was fed with the data collected using the field survey sheets. The capabilities of the proposed PASS index and the corresponding GIS model will be presented and the results will be discussed in the following section at five different spatial levels.

Results and Discussion

As mentioned above, the overall walkability index score consists of four components. Using the GIS model each component was calculated using equations 2 to 5, and the overall PASS index value was calculated by the GIS model using Equation 1. The way the PASS index is constructed allows researchers, experts, and engineers to analyze the results in different ways and at different spatial levels including: (1) Components and overall PASS analysis; (2) Road and segment level; (3) Road network level; (4) Neighborhood and district level; and (5) City level. We tested the model using the data collected from Nablus city and we obtained results at five spatial levels as follows:

(1) Walkability components and overall PASS analysis

Overall results indicate very low values on all four indicators, as shown in Table (3) below. The worst is the special needs component with 81% of the road segments satisfying none of the special needs requirements. No segments obtained a score of 3 or more, which indicates almost complete neglect of the special needs requirements in the study area. The safety component is not much better than the special needs component. None of the street segments obtained a score of 4 or more for the safety component, and the majority of road segments obtained scores of 1 and 2 with 53% and 32%, respectively.

A better component, in terms of good performance, is the aesthetic component in which 69% of the road segments obtained a score of 3. The aesthetic component, however, is still low at a score of 5 which was obtained by only 4% of total road segments. Finally, the physical design component is the only component that does well at a score of 5 achieved by 20% of the road segments.

Table 3. Results of Walkability components and overall PASS analysis

Component Score	Physical Design	Aesthetic and Convenience	Safety	Special Needs Requirements	PASS index
0	2%	1%	7%	81%	23%
1	30%	0%	53%	17%	25%
2	40%	17%	32%	1%	23%
3	5%	69%	7%	0%	20%
4	3%	9%	0%	0%	3%
5	20%	4%	0%	0%	6%

As to the overall PASS index score, 3% of the road segments obtained a score of 4, and 6% of the segments obtained a score of 5. This is a very low score indicating a general weakness in the walkability performance. One of the manifestations of the poor performance of the Index is that nearly one-fourth of the roads (23%) received a score of 0, and the same percentage received a score of 1. These results mean that one-half of the roads did not meet the minimum walkability requirements in the study area. In the same context, less than one-half of the streets have index values between 3 and 2. The low performance of the index is due to the low values of the four components, as discussed previously.

(2) Analysis at segment and road level

PASS analysis at a single road segment and road level enables planners and engineers to conduct detailed analysis at the micro level. Each road segment has a unique ID and a PASS score that can be aggregated up to the road level as shown in Figure (5). Analysis at this level enables engineers to develop mechanisms for localized interventions that can be implemented in short time and with limited budgets.

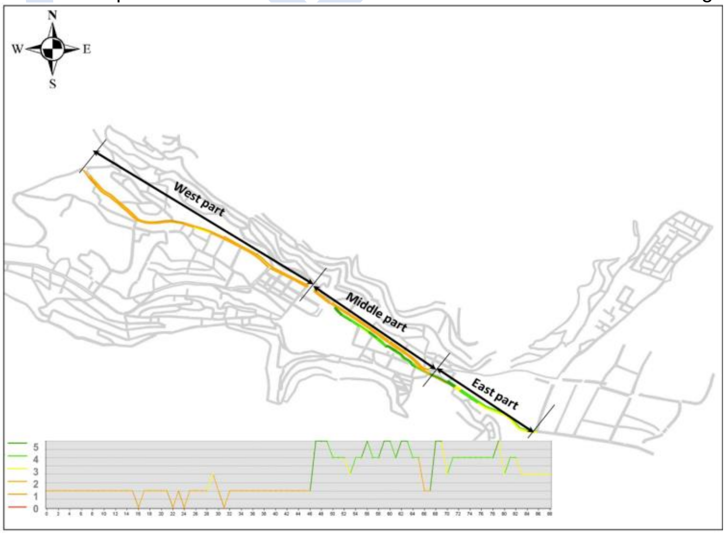


Figure 5. Sample of PASS analysis output at segment and road level

Table 4. Average scores of PASS index and its components for Faisal street

Road Type	Physical Component	Aesthetic and Convenience	Safety Component	Special Needs Component	PASS Index
West	2.1	2.6	2.21	0.17	1.9
Middle	3.75	3.18	1.8	0.3	3.3

East	4.6	3.15	2.3	0.25	3.6

In the example shown above, Faisal street is the main arterial in Nablus city with shops lining on both sides of the streets, sidewalks, and other pedestrian amenities. While the Physical and Aesthetic components scores are highly ranked for the street, the resulting PASS index score is lowered by the Safety and Special Needs components. It is obvious that the PASS index varies along the main arterial so municipalities can use PASS index as a useful planning tool to prioritize interventions at road segment and road section level.

(3) Analysis at the road network level

The road network, in general, shows very low levels of walkability as the results in Table (5) tell us. The road network is classified into three types of roads: Arterials, Collectors, and Locals. The aesthetic and convenience components achieved the highest values for the three types of roads, while the physical and design components achieved moderately high score values for arterials and collectors. Local streets suffer from weak physical design conditions, which call for appropriate actions from the municipality.

As to the safety component, the best road class is the Arterial with an average of 2.04 out of 5 while the collectors and the local roads achieved only 1.54 and 1.4 points, respectively. These results, in fact, show a serious problem in the safety procedures in the study area, which affects the overall walkability score. The special needs component is the worst as it achieved only 0.3 points in best performance for the collectors. The arterials and locals, on the other hand, achieved 0.2 and 0.19 points, respectively. This is an indication of complete neglect of the special needs regardless of the road type, which also affects the overall score of PASS index.

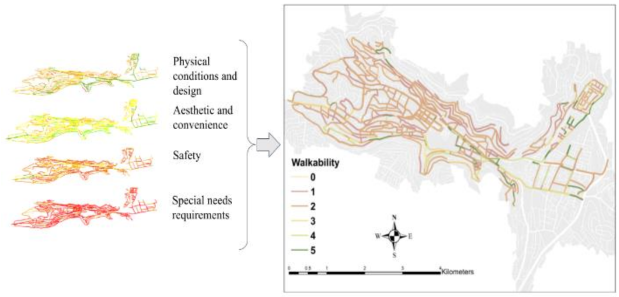
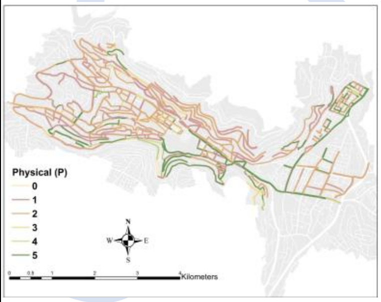


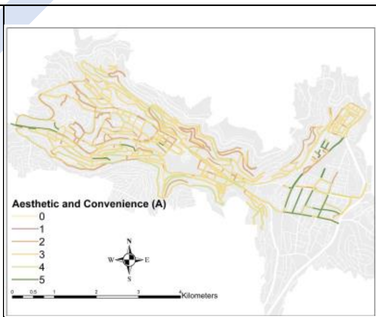
Table 5. Average scores of PASS index and its components for the three types of roads

Road Type	Physical Component	Aesthetic and Convenience	Safety Component	Special Needs Component	PASS Index
Arterial	3.00	3.6	2.04	0.2	2.2
Collector	3.1	3.6	1.54	0.3	2.1
Local	2.3	3.3	1.4	0.19	1.8

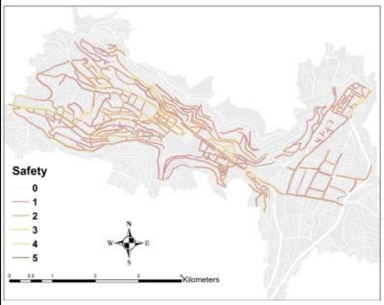
As to the final PASS scores, the low score values of the four components are, by default, reflected on the overall walkability scores. Arterials are doing better with 2.2 score than collectors and locals with scores of 2.1 and 1.8, respectively. The scores in table (5)—and referring to the spatial distributions shown in figure (6) below—guide the planners and engineers to decide the types and quantities of interventions to improve the walkability.



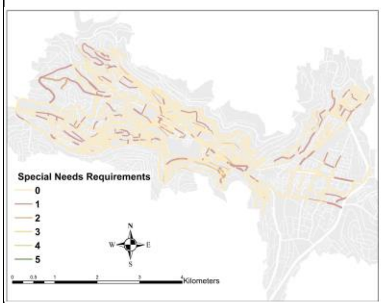
a. Physical Component



b. Aesthetic and Convenience



c. Safety Component



d. Special needs Component

Figure 6. Sample of PASS analysis output at road network level

(4)Analysis at neighborhood and district level

PASS is designed in a way that enables planners and engineers to conduct analysis at district and neighborhood level based on land uses or any spatial factor. Walking strategies are usually concentrated where people live (residential areas), learn (universities and school districts), work and shop (CBD), and play and stroll (recreation districts). In our case, five districts were selected to examine PASS capabilities at neighborhood and district levels as shown in Figure (7) below.

The five districts were selected based on their land uses and for their importance for the pedestrians including:

(1) the university district (EDU) where two campuses of An-Najah National University are available; (2) a residential area (RES); (3) the recreational district (REC) where the main urban park and the sport stadium of the city is available; (4) the CBD area at the city center; and (5) the school district and governmental district (SCH) where five schools and governmental directorates are available.

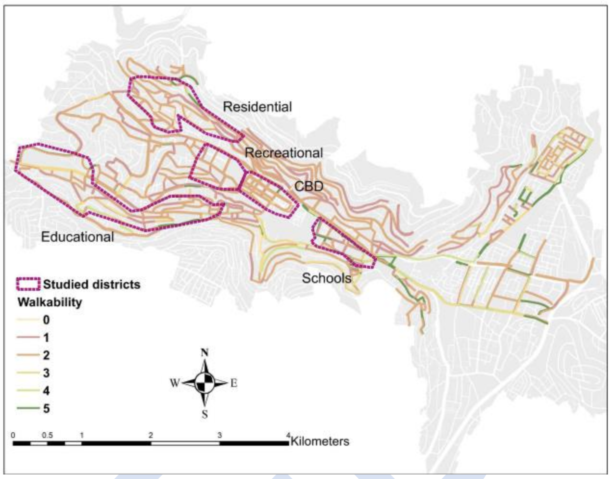


Figure 7. PASS analysis at neighborhood and district level

Results at district level show no significant difference among the five districts. None of the districts achieved high or moderate overall PASS scores except the school district with 2.58 points. EDU is the best in Aesthetics and Convenience with 3.1 points, while the CBD is the best in safety. Special needs requirements are the worst for all districts, which is consistent with other levels of analysis showing similar results.

Table 6. Average scores of PASS index and its components for five districts

Land Use	Physical Component	Aesthetic and Convenience	Safety Component	Special Needs Component	PASS Index
EDU	2.22	3.1	1.5	0.21	2.1
RES	1.75	2.7	1.25	0.22	1.69
REC	2.02	2.83	1.64	0.13	1.78
CBD	2.27	2.84	2.04	0.21	2
SCH	2.87	3	1.53	0.31	2.58

(5) City level

An additional advantage of the proposed index is that PASS can be generated at the city level. By aggregating the index value from the road segment to the city level, we can obtain one value for the whole city. In our case, the PASS value for Nablus city = 2.13 which is a very low value and calls for action from the municipality at the city level. The same methodology can be followed in other cities and each city will have its own PASS score. Consequently, we can compare the indices values to decide what policies and strategies are required at the national level and where to concentrate the improvement and development programs.

Table 7. Average scores of PASS index and its components for Nablus City

Physical Component	Aesthetic and Convenience	Safety Component	Special Needs	PASS Index
2.39	2.94	1.49	0.2	2.13

Conclusion

The proposed walkability index PASS is a multi-component quantity. The index consists of four elements representing all dimensions of walkability including: physical design component, aesthetic and convenience component, safety, and special needs requirement components. PASS was tested in Nablus city and found to be an effective tool in quantifying and presenting walkability at four spatial levels: (1) road and road segment level; (2) road network level; (3) neighborhood and district level; and (4) city level.

The results of the case study show that PASS index and the accompanied GIS model are powerful tools for walkability analysis at the four spatial levels. PASS analysis at a single road segment and road level enables planners and engineers to conduct detailed analysis and make decisions micro level. At a higher spatial level, the proposed index PASS can be used to identify the quality of walkability neighborhood and district levels such as CBD areas, university districts, and school zones. Therefore, decision-makers, planners, and engineers can benefit from the proposed methodology to identify where interventions are required and to prioritize budget allocation to improve the walking environment in these areas.

At the road network level, PASS index analysis enables engineers to conduct specialized analysis based on road functional classes including arterials, collectors, and locals, which enables engineers to develop mechanisms for localized interventions.

At the upper spatial level, PASS can be conducted at the city level and has the potential to be conducted at the national level. If the same methodology is applied in other cities, PASS can be a powerful comparative tool to compare walkability among different cities at the national level. Consequently, we can compare the indices values to decide what policies and strategies are required at the national level and where to concentrate the improvement and development programs.

Finally, this research is a significant methodological contribution as it can be easily replicated in other cities with limited financial and technical resources. It is a simple methodology and can be implemented within GIS environment in any municipality. Using PASS, decision-makers and engineers can make wise decisions about where and how to start improving the walking environment in their communities with the least financial and technical efforts.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable

Availability of data and materials

The raw data required to reproduce these findings are available in the body and illustrations of this manuscript.

Author's contribution

The authors confirm contribution to the paper as follows: study conception and design: E. Dawwas, theoretical calculations and modeling: E. Dawwas and A. Hilal; data analysis and validation, E. Dawwas and A. Hilal. draft manuscript preparation: E. Dawwas and A. Hilal. All authors reviewed the results and approved the final version of the manuscript.

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Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this article

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