# Evaluation of the pedestrian infrastructure using walkability indicators

ATHANASIOS GALANIS, NIKOLAOS ELIOU
Department of Civil Engineering
University of Thessaly
Pedion Areos, Volos
GREECE
atgalanis@uth.gr, neliou@uth.gr

*Abstract:* - The promotion of pedestrian safety, mobility and convenience is an important step to raise sustainable mobility in urban areas. This study presents the development and implementation of indicators that evaluate pedestrian infrastructure in urban streets. The study area was six selected roads in the city of Volos, Greece. The roads were characterized as main, collector or local urban arterials, located inside or close to the center of the city. Four suitably trained authors walked across the streets, took pictures and charted the pedestrian infrastructure for each side of the street and each road segment and crosswalk. The auditors' team included three undergraduate students as the team members and a PhD candidate as the team leader. After this step, the auditors created a drawing of the pedestrian infrastructure and counted indicators for road segments, street corners and crosswalks. The road segment indicators were split into two categories: the infrastructure ones and the street furniture ones. The result of the study was to compare the pedestrian infrastructure of the streets in terms of walkability and evaluate the convenience of pedestrians to walk on their desire route across the streets. The outcome of this study was that these indicators could be used in a pedestrian walkability study in order to notice the main problems of pedestrian infrastructure and propose focused remedial actions.

*Key-Words:* - Pedestrian infrastructure, Indicators, Road segment, Corner, Crosswalk, Walkability, Sustainability

## 1 Introduction

This study examines the pedestrian infrastructure in urban streets using walkability indicators in the framework of sustainability. Walking is a sustainable transport mode and community authorities all over the world are on continuous pressure to provide their citizens with highly walkable streets. One of the best steps to deal this problem is the development and implementation of walkability indicators focused on pedestrian infrastructure. The results of this study can help decision makers and planners to audit the pedestrian infrastructure and propose focused remedial actions.

### 1.1 Sustainable transportation

Sustainable transport modes contribute into the environmental, social and economical sustainability of the modern societies. A transportation system serves the demand of personal contact. The benefits of mobility rising should balance the environmental, social and economic cost that a transport mode or system provides.

There is no commonly accepted definition of sustainable transportation. According to the "Organization for Economic Cooperation and Development" (OECD) and the Canadian "Center for Sustainable Transport" (CST) a sustainable transport system is the one that [1], [2]:

- Serves the needs of accessibility and mobility in personal and society level with respect on human and environment, targeting to balance the needs of presence and future needs
- Is sufficient and effective, offers alternative choices of transport modes, supports a competitive economy and a balanced territorial development
- Reduces the emissions, uses alternative power resources and minimizes the used space

### 1.2 Sustainable transportation indicators

The definition of sustainable transportation was the first step towards the development of sustainable transportation indicators. There is a common sense that "anything that can be counted can be managed". Sustainable transportation indicators include at least two of the three columns of sustainability [3]. An indicator should not only count a phenomenon but should also create a data base for a future evaluation. Sustainable transportation can be evaluated with several indicators focused on the three columns of sustainability [4].

#### 1.2.1 Economical indicators

These indicators include the cost and the income of the transport modes. The promotion of one transport mode can minimize the network mobility and the intermodality. The amount of kilometers per vehicle or passenger could be such an indicator if the examined transport mode is harmful for the environment [5]. But this hypothesis is not completely correct because the rising of accessibility of an area promotes economical development.

The economical impact of a transportation mode is related to the existing infrastructure. In USA, the urban design promotes car use due to urban sprawl, large urban highways and parking areas in center business districts. About 30% of transportation with cars could relate to these factors [6].

Some decisions can be evaluated according to their sustainability impacts. Actions that reduce traffic flow and urban sprawl are not sustainable but investment on pedestrians, bicyclists and public transport are sustainable.

Finally, a transport mode in order to be economical sustainable should incorporate the entire external cost. Walking is a transport mode with minimum external cost and due to this factor is consider highly sustainable.

#### 1.2.2 Social indicators

The impact of a transport mode on the society can be evaluated with factors as the respect on public needs, the reduction of the negative impacts on public health and environment. The target is to achieve access on the entire road network with safety and convenience. Furthermore, the target is the ability to each citizen to use the transport mode. All pedestrians and bicyclists should be able to walk and bike with safety and convenience is the entire road network of a city. The providence of a proper infrastructure is an indicator of this theme.

#### 1.2.3 Environmental indicators

The environmental indicators evaluate the impact of a transport mode to the environment. There are many methodologies related to these impacts that cannot use every available factor in order to have reliable conclusions [7].

### 1.3 Sustainable environment indicators

Many projects have implemented in order to evaluate which are the main indicators of a sustainable city. In the city of Seattle (USA) in 1992 implemented a project in order to evaluate the sustainability footprint of the city using sustainable indicators [8].

Urban sustainability indicators vary geographically from global to city scale. The energy a city consumes the quality of the air, the urban sprawl and the green open space could be significant indicators of an urban sustainability evaluation [9].

The European research program “Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability” (PROPOLIS) has developed significant urban sustainability indicators [10]. It presents 9 main sections with 35 indicators based on the three columns of sustainability. According to this project, only a significant increase of the motorized transportation cost could reduce the global warming gas emissions.

The development of a database system is necessary in order to monitor the environmental quality of the urban road network and support decision making process of local authorities. A geodatabase connected with a Geographical Information System (GIS) can be created, including all collected indices [11].

The promotion of renewable energy is a main target in many countries of the European Union [12]. Furthermore, the concept of sustainable development is a key point of a development of a country or a region not only on economic issues, but also social, environmental, political, legal and cultural issues [13], [14].

### 1.4 The concept of walkability

Citizens desire to live in a city where they will be able to walk with safety and convenience. Cities that are suitable to walking (walkable city) have many benefits for their citizens, such as:

- A road network safe for pedestrians
- Better accessibility to destinations for all
- Selection of multiple transportation modes
- Better health for their citizens

The definition of walkability is not specific but can be explained as the suitability that the urban road environment offers to pedestrians. The walkability level differs among urban areas and cities. There are many differences related to economical, cultural and topographical factors. Pedestrians should be able to walk in the entire urban road network in order to reach their destinations. The basic features of a walkable urban road environment are the following:

- Accessibility
- Convenience
- Attractiveness

- Road safety
- Personal safety

The promotion of walkability can improve the quality of life in urban areas and raise the sustainability footprint of the city.

### 1.5 The relationship of walkability and the built environment

A lot of research is conducted to examine the relation between the urban road environment features and factors like the selection of transport mode, the citizens' physical activity and the level of road safety. Ball et al (2001) considered that recreational walking relates on the attractivess and convenience of the urban road environment [15]. Hoehner et al (2005) examined features related to higher physical transportation in high and low walkable cities in USA. They examined the land use, the recreational areas, the road network and social factors. They concluded that more citizens living in a high walkable city are willing to walk [16].

Powell et al (2003) examined the relation between physical activity and the urban environment in neighborhood areas. They considered that there is a strong relation between convenience and the level of walking. Furthermore, they concluded that the short distance of the destination raises the level of walking [17].

Cervero and Duncan (2003) examined the urban road environment features in the city of San Francisco, USA [18]. They concluded that the main factors that influence the level walking were the distance of the route, the topography, the weather condition and the neighborhood features. They concluded that mixed land use and work places relate strongly on the level of walking.

Craig et al (2002) examined the factors that influence walking among adult citizens in Canada [19]. They resulted that the absence of obstacles across the pedestrians' desire route, the maintenance level, the road safety, the personal security, the directness and selection of the routes related to the level of walking.

Jacobsen (2003) concluded that the pedestrian road safety level rises as the pedestrian traffic flow also rises [20]. The 100% of the pedestrian traffic flow relates on a decrease of 32% in road accidents.

According to the literature it is very difficult to recognize and quantify the relation between the urban road environment features and the level of walking. The main factors are the accessibility of a destination, the type and mix of land use, the convenience and maintenance of the pedestrian infrastructure and the pedestrian road and personal safety.

## 2 Methodology

The improvement of pedestrian safety, mobility and convenience is an important step for the promotion of sustainable transportation in urban areas. This study examines the pedestrian infrastructure in urban streets using walkability indicators in the framework of sustainability.

### 2.1 Study area

The study area consisted of six urban roads located inside or close to the center of the city (Fig.1):

- Iasonos St (Main Arterial)
- Kartali St (Main Arterial)
- 28 October St (Collector Arterial)
- Gazi St (Collector Arterial)
- Korai St (Collector Arterial)
- Diakou St (Local Street)

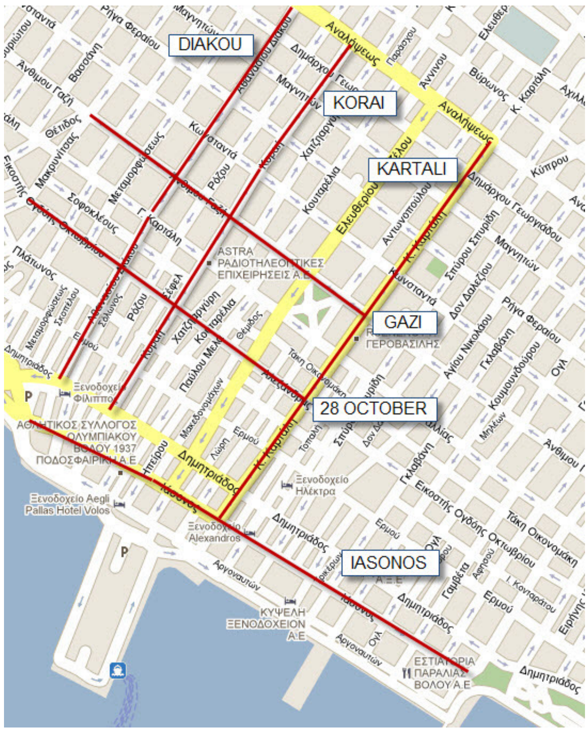


Fig.1: Study Area (Center of the city)

### 2.2 Street coding

The streets were separated into road segments and crosswalks with identification codes for each one. The street was separated into two sides: "Side A" and "Side B". Iasonos St consisted of 16 road segments in Side A and 28 in Side B. 28 October St consisted of 15 road segments in Side A and 13 in Side B. Gazi St consisted of 10 road segments in both sides of the street. Kartali St consisted of 12 road segments in both sides of the street. Korai St consisted of 10 road segments in Side A and 11 in Side B. Finally, Diakou St consisted of 11 road segments in Side A and 13 in Side B. This difference was created from the length of each road segment and its identification. We kept the same codes for opposite road segments (e.g. 8A, 8B) but we put subcodes if subsegments were noticed (e.g. 1A, 1B1, 1B2), (Fig. 2). We named the crosswalks according to the nearby road segments codes. So, the crosswalk 1B2_2B1 was the crosswalk located between the road segments 1B2 and 2B1 (Fig.2).

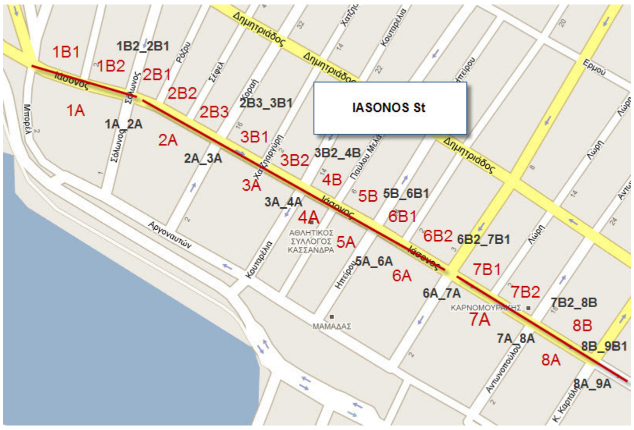

Fig.2: Street coding

### 2.3 Selection and training of the auditors' team

The auditors' team included three undergraduate students as the team members and a PhD candidate as the team leader. The team leader explained the target of the study and the topographical charting way to the team members. The team charted a typical road segment and a crosswalk in order to get used to the process. After the training the team members were ready to implement the study in the field.

### 2.4 Data collection and charting

The auditors walked across the streets during Sunday morning when the pedestrian and vehicles' traffic flow was limited. The target was to chart the pedestrian infrastructure in each road segment and crosswalk without being annoyed from road users or land owners. The auditors used the following tools:

- Street map with identification codes
- Meter
- Pens and pencils
- Camera

The auditors took also many pictures of the pedestrian infrastructure and street furniture in order to help them in the charting process in the office.

After the data collection the auditors formed the drawing of the pedestrian infrastructure in CAD software (Fig.3, 4). The drawing can be part of a walkability study deliver package. It should be reliable containing as much information as possible. One critical detail was the presence of the photos the auditors took into the drawing. Each photo is presented with a specific way: "<F...n". "F" is the name of photo, "n" is the number of the photo and "<" is the heading. In walkability audit studies all the photos should be delivered in the appendix of the study.

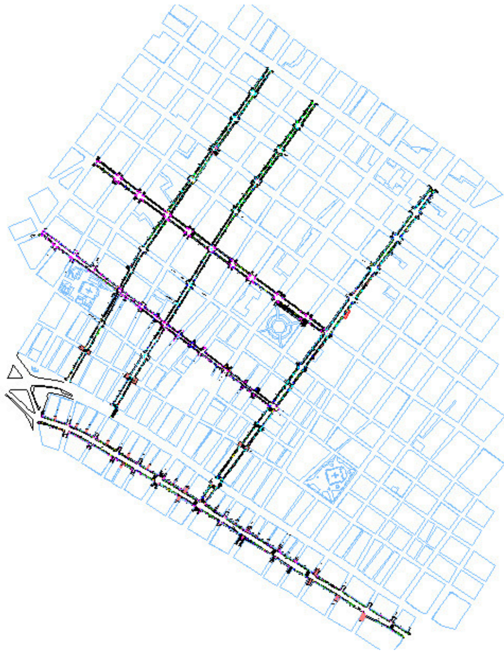
Fig.3: Drawing (study area)

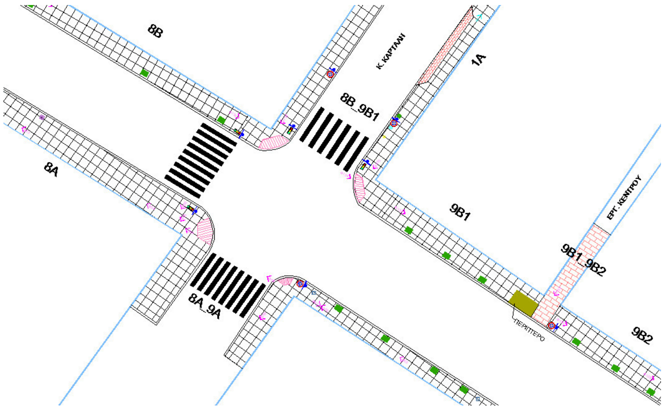

Fig.4: Drawing (Intersection Iasonos-Kartali St)

## 3 Results

### 3.1 Description of indicators

The evaluation of the walkability level of an urban street can be achieved with the implementation of a checklist for road segments, crosswalks, bus stop shelters etc. During a walkability audit process the charting of pedestrian infrastructure and the counting of walkability indicators is necessary. These indicators can create a quantitative image of the pedestrian urban environment.

Tables 1-4, present the walkability indicators in road segments (Tables 1, 2), corners (Table 3) and crosswalks (Table 4). The road segment indicators are split into two categories:

- Pedestrian infrastructure indicators: No1-No9 (Table 1)
- Street furniture indicators: No10-No22 (Table 2)

The concept was to identify the width of the pedestrian desire route. Furthermore, indicate which the main mobile obstacles on the sidewalks are. The sidewalk area (No1) is a very important indicator but is related to the length of the road segment (No2). The indicator No5 describes the continuous of the sidewalk across the road segment. The indicator No8 describes the clearness of the pedestrian width due to presence of permanent obstacles. The indicator No9 describes the outlier of the clear pedestrian route according to the maximum sidewalk width in the road segment.

Table 1: Road segment indicators (No1-No9)

| Pedestrian infrastructure indicators | |
|---|---|
| 1 | Sidewalk area (m2) |
| 2 | Road segment length (m) |
| 3 | Sidewalk maximum width (m) |
| 4 | Sidewalk minimum width (m) |
| 5 | Min/Max sidewalk width (%) |
| 6 | Maximum unobstructed width (m) |
| 7 | Minimum unobstructed width (m) |
| 8 | Min/Max unobstructed width (%) |
| 9 | Min unobstructed/ max sidewalk width (%) |

The indicators No10-No19 describe the amount of street furniture in each road segment. They refer to the area covered from trees (No10), lighting poles (No11), traffic signs and signals (No12), shelters for public transport modes (bus stop shelters) (No13), kiosks (No14), and baskets for litter (No15) and benches (No16). The indicator No17 describes the total amount of the street furniture area presented on a sidewalk of a road segment. The indicator No18 excludes kiosks and the indicator No19 excludes public transport shelters. These indicators can help researchers to compare similar street furniture indices across the road segments of a street. The indicators No20-No22 count the street furniture area as a percentage of the total sidewalk area.

These indicators can describe the walkability features of the street. The presence of trees relates to the attractiveness and weather protection of the pedestrians. The presence of litter baskets relates to the cleanliness and benches to the convenience. Bus stop shelters can promote the intermodality and sustainable transportation but their presence could be a major obstacle across the pedestrian desire line of pedestrians forcing them to walk in the street reducing the level of road safety.

Table 2: Road segment indicators (No10-No22)

| Street furniture indicators | |
|---|---|
| 10 | Trees area (m2) |
| 11 | Lighting poles area (m2) |
| 12 | Traffic sign and signal poles (m2) |
| 13 | Public transport shelters area (m2) |
| 14 | Kiosks area (m2) |
| 15 | Litter baskets area (m2) |
| 16 | Bench area (m2) |
| 17 | Permanent street furniture (m2) |
| 18 | Permanent street furniture except kiosks (m2) |
| 19 | Permanent street furniture except kiosks and public transport shelters (m2) |
| 20 | Permanent street furniture/ sidewalk area (%) |
| 21 | Permanent street furniture except kiosks/ sidewalk area (%) |
| 22 | Permanent street furniture except kiosks and public transport shelters/ sidewalk area (%) |

The corner indicators are presented in Table 3. They describe the corner area (No1), the street furniture area (No2) and the ramp area (No3) and their percentages (No4-5). The crosswalk indicators for the crosswalk length (No1), width (No2) and covered area (No3) are presented in Table 4.

Table 3: Corner indicators

| Corner indicators | |
|---|---|
| 1 | Corner area (m2) |
| 2 | Street furniture area (m2) |
| 3 | Ramp area (m2) |
| 4 | Street furniture/ corner area (%) |
| 5 | Ramp/ corner area (%) |

Table 4: Crosswalk indicators

| Crosswalk indicators | |
|---|---|
| 1 | Crosswalk length |
| 2 | Crosswalk width |
| 3 | Crosswalk area |

## 3.2 Road segment indicators

The results of the implementation of the road segment indicators are presented in Tables 5-8. In Table 5, is presented the average rate of the infrastructure indicators No1-No9 and in Table 6 the standard deviation of these indicators. In Table 7, is presented the average of the street furniture indicators No10-No22 and in Table 8 the standard deviation of these indicators. The average rate of each indicator refers to the both road segment of the streets. The indicators can be presented for each road side separately (Side A or Side B) or as an average among them for the entire street (Average AB). The standard deviation rate can explain the difference of each indicator rate among the road segments. Low standard deviation refers to a homogenous pedestrian infrastructure.

Table 5: Infrastructure indicators (Average)

| Indicators | Iasonos | 28 October | Gazi | Kartali | Korai | Diakou |
|---|---|---|---|---|---|---|
| | AVERAGE (AB) | | | | | |
| 1 | 88,2 | 46,60 | 122,4 | 163,0 | 110,8 | 99,21 |
| 2 | 34,1 | 33,96 | 58,13 | 48,72 | 64,77 | 54,33 |
| 3 | 2,65 | 1,42 | 2,48 | 3,18 | 1,85 | 2,19 |
| 4 | 2,40 | 1,36 | 1,93 | 2,75 | 1,72 | 1,70 |
| 5 | 0,94 | 0,97 | 0,75 | 0,86 | 0,93 | 0,79 |
| 6 | 2,65 | 1,40 | 2,48 | 2,40 | 1,65 | 2,14 |
| 7 | 1,48 | 1,19 | 1,46 | 1,65 | 0,92 | 1,08 |
| 8 | 0,58 | 0,85 | 0,56 | 0,69 | 0,66 | 0,52 |
| 9 | 0,58 | 0,84 | 0,56 | 0,53 | 0,53 | 0,50 |

Table 6: Infrastructure indicators ($R^2$)

| Indicators | Iasonos | 28 October | Gazi | Kartali | Korai | Diakou |
|---|---|---|---|---|---|---|
| | $R^2$ (AB) | | | | | |
| 1 | 23,6 | 17,40 | 53,9 | 53,06 | 26,27 | 44,79 |
| 2 | 10,3 | 12,73 | 8,86 | 12,66 | 11,74 | 9,75 |
| 3 | 0,47 | 0,12 | 0,69 | 0,51 | 0,53 | 0,74 |
| 4 | 0,35 | 0,09 | 0,73 | 0,66 | 0,56 | 0,65 |
| 5 | 0,15 | 0,07 | 0,10 | 0,12 | 0,11 | 0,12 |
| 6 | 0,47 | 0,10 | 0,69 | 0,46 | 0,72 | 0,79 |
| 7 | 0,41 | 0,10 | 0,59 | 0,49 | 0,19 | 0,42 |
| 8 | 0,14 | 0,05 | 0,09 | 0,17 | 0,29 | 0,21 |
| 9 | 0,14 | 0,06 | 0,09 | 0,13 | 0,15 | 0,20 |

Table 7: Street furniture indicators (Average)

| Indicators | Iasonos | 28 October | Gazi | Kartali | Korai | Diakou |
|---|---|---|---|---|---|---|
| | AVERAGE (AB) | | | | | |
| 10 | 1,902 | 0,056 | 0,800 | 1,696 | 1,274 | 3,678 |
| 11 | 0,097 | 0,033 | 0,146 | 0,175 | 0,028 | 0,187 |
| 12 | 0,221 | 0,061 | 0,031 | 0,156 | 0,083 | 0,024 |
| 13 | 0,519 | 0,000 | 0,000 | 1,097 | 0,000 | 0,000 |
| 14 | 0,662 | 0,000 | 0,188 | 0,853 | 0,000 | 0,000 |
| 15 | 0,267 | 0,090 | 1,494 | 0,202 | 0,595 | 0,015 |
| 16 | 0,000 | 0,000 | 0,450 | 0,000 | 0,000 | 0,123 |
| 17 | 3,669 | 0,240 | 3,108 | 4,180 | 1,980 | 4,028 |
| 18 | 3,007 | 0,240 | 2,921 | 3,327 | 1,977 | 4,028 |
| 19 | 2,487 | 0,240 | 2,921 | 2,230 | 1,977 | 4,028 |
| 20 | 0,041 | 0,005 | 0,028 | 0,027 | 0,018 | 0,048 |
| 21 | 0,033 | 0,005 | 0,026 | 0,020 | 0,018 | 0,048 |
| 22 | 0,028 | 0,005 | 0,026 | 0,013 | 0,018 | 0,048 |

Table 8: Street furniture indicators ($R^2$)

| Indicators | Iasonos | 28 October | Gazi | Kartali | Korai | Diakou |
|---|---|---|---|---|---|---|
| | $R^2$ (AB) | | | | | |
| 10 | 0,903 | 0,119 | 0,367 | 1,259 | 1,293 | 4,660 |
| 11 | 0,076 | 0,088 | 0,204 | 0,115 | 0,052 | 0,439 |
| 12 | 0,203 | 0,029 | 0,032 | 0,110 | 0,061 | 0,035 |
| 13 | 0,678 | 0,000 | 0,000 | 1,635 | 0,000 | 0,000 |
| 14 | 1,037 | 0,000 | 0,395 | 1,655 | 0,000 | 0,000 |
| 15 | 0,321 | 0,208 | 1,835 | 0,532 | 0,900 | 0,060 |
| 16 | 0,000 | 0,000 | 1,423 | 0,000 | 0,000 | 0,482 |
| 17 | 1,415 | 0,365 | 2,592 | 2,700 | 0,906 | 4,491 |
| 18 | 1,075 | 0,365 | 2,437 | 2,126 | 0,909 | 4,491 |
| 19 | 0,980 | 0,365 | 2,437 | 1,348 | 0,909 | 4,491 |
| 20 | 0,021 | 0,008 | 0,025 | 0,019 | 0,009 | 0,071 |
| 21 | 0,013 | 0,008 | 0,024 | 0,011 | 0,009 | 0,071 |
| 22 | 0,011 | 0,008 | 0,024 | 0,005 | 0,009 | 0,071 |

According to the results of the indicator No1, the sidewalk area differs among the streets (Fig.5). The maximum rate was noticed in Kartali St ($163m^2$) and the minimum in 28 October St ($46.6m^2$). These results can be explained from the average length of the road segments of the streets (indicator No2) and the average sidewalk width.

The indicator No5 refers to the min/max rate of the sidewalk constructed width across the road segments of the streets (Fig.6). The highest rate was noticed in 28 October St (0.97) and the lowest in Gazi St (0.75).

Similarly, the indicator No8 describes the min/max unobstructed sidewalk width (Fig.7). This is actually the clear width of the pedestrian route across the sidewalks of the street. The presence of street furniture reduces the rate of this indicator. The highest rate was noticed in 28 October St (0.85) and the lowest in Diakou St (0.52). If we exclude the 28 October St we conclude that the average rate of this indicator is 0.60. This means that the clear route for pedestrians is only the 60% of the sidewalk width. The outlier of this rate is described from the indicator No9 (Fig.8). If we exclude the 28 October St, in the rest streets the rate of this indicator is about 0.55. This rate means that as an average only the 55% of the sidewalk width can be used from pedestrians due to presence of permanent obstacles or street furniture.

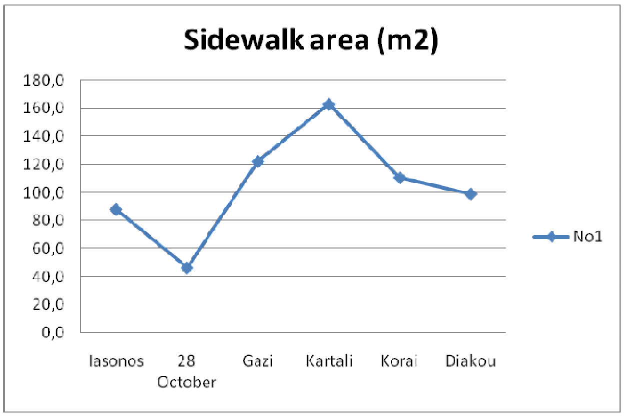


Fig.5: Road segment indicator No1

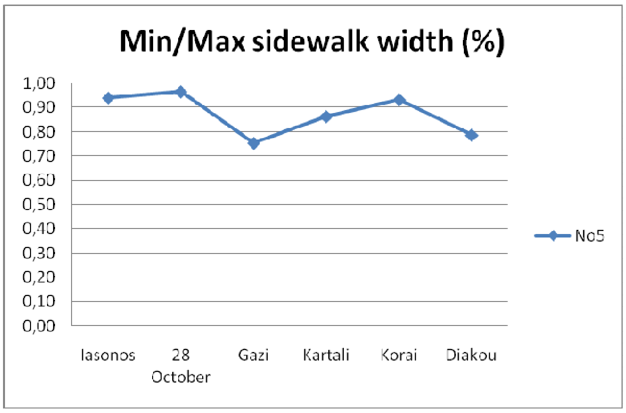


Fig.6: Road segment indicator No5

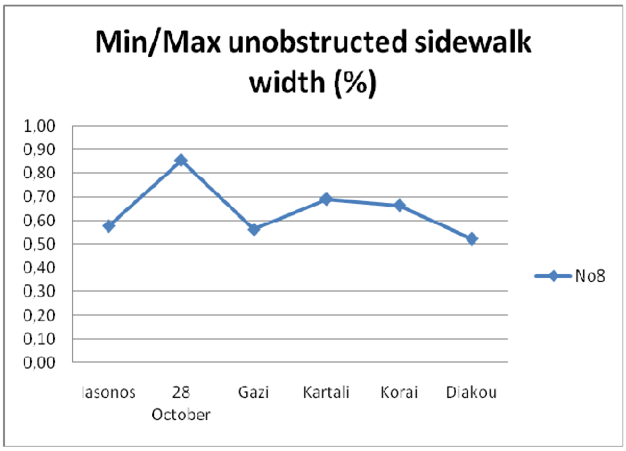


Fig.7: Road segment indicator No8

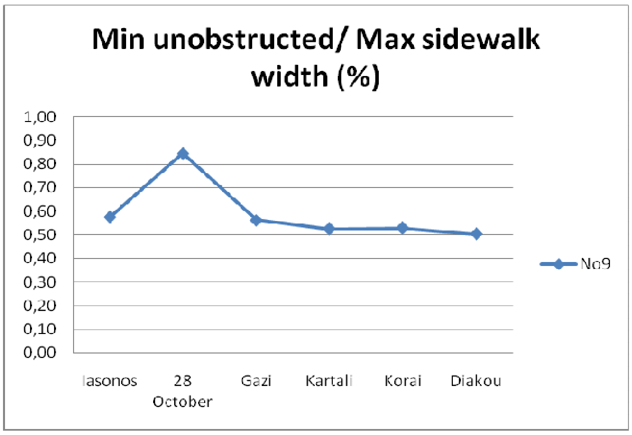


Fig.8: Road segment indicator No9

The presence of street furniture across a road segment is very important for pedestrians and motorists. The critical point is not only the amount of this equipment but also its location separately from the pedestrian desire route. The indicator No20 describes the area that covers the street furniture as a percentage of the total sidewalk area across the road segments (Fig.9). The results differ among the streets. The highest rate was noticed in Diakou St (0.048) and Iasonos St (0.041) and the lowest rate in 28 October St (0.005).

The street furniture is not the same in each street. The presence of bus stop shelters and kiosks can significantly increase the amount of street furniture and create “black points” or “low walkability sites” across the pedestrian desire route. Indicator No22 describes the amount of street furniture on the sidewalk across a road segment excluding the public transport (bus) stop shelters and kiosks (Fig.10). The main reduce in the street furniture percentages was noticed in Iasonos St (from 0.041 to 0.028) and in Kartali St (from 0.027 to 0.013). The highest and steady rate was noticed in Diakou St (0.048). These rates indicate that the 1%-5% of the sidewalk surface is covered from street furniture.

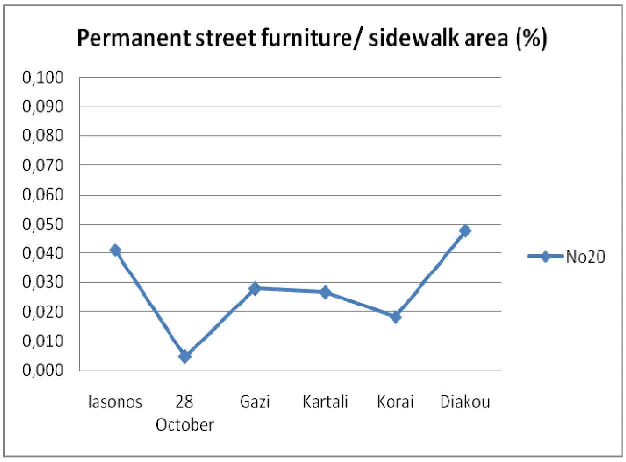


Fig.9: Road segment indicator No20

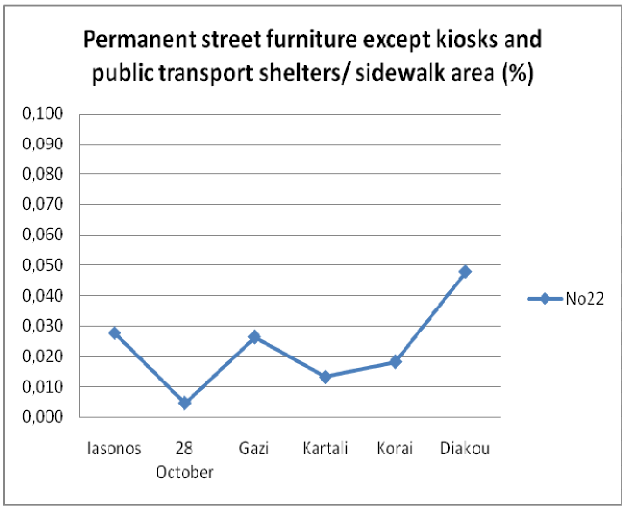


Fig.10: Road segment indicator No22

### 3.3 Corner indicators

The results of the implementation of the corner indicators are presented in Table 9. We present the average rate of each indicator and the maximum and minimum rates of the corners of both road segments across the streets.

The indicator No1 describes the corner area (Fig.11). The highest rate was noticed in Kartali St (5.8m$^2$) and the lowest in 28 October St (1.78m$^2$). This indicator is closely related with the sidewalk width across the street. In the rest of the streets we noticed an average rate of 4m$^2$ covered from the crosswalk corner.

The indicator No4 describes the percentage of the street furniture are in the corner area (Fig.12). The highest rate was noticed in 28 October St (0.046) and the lowest rate in Iasonos St (0.004).

The indicator No5 describes the percentage of the ramp area in the corner area (Fig.13). The providence of ramps is very important for the walking convenience across the road segment-crosswalk route. Furthermore, the ramps create a road space where motorists cannot park their vehicles and pedestrians can stand before crossing the street. The highest rate was noticed in Iasonos St (0.405) where almost each corner was provided with ramps raising the walkability level of the street. On the contrary, the lowest rate was noticed in 28 October St (0.00) where no ramp was noticed.

Table 9: Corner indicators

| Indicators | Iasonos | 28 October | Gazi | Kartali | Korai | Diakou |
|---|---|---|---|---|---|---|
| | AVERAGE (AB) | | | | | |
| 1 | 3,903 | 1,787 | 4,702 | 5,819 | 4,171 | 4,069 |
| 2 | 0,016 | 0,075 | 0,096 | 0,110 | 0,289 | 0,106 |
| 3 | 1,573 | 0,000 | 0,085 | 0,476 | 0,230 | 0,194 |
| 4 | 0,004 | 0,046 | 0,019 | 0,031 | 0,014 | 0,034 |
| 5 | 0,405 | 0,000 | 0,023 | 0,103 | 0,023 | 0,044 |
| | MAX (AB) | | | | | |
| 1 | 6,600 | 4,470 | 10,723 | 7,355 | 12,575 | 11,290 |
| 2 | 0,080 | 0,250 | 0,665 | 0,160 | 0,985 | 0,656 |
| 3 | 2,897 | 0,000 | 0,765 | 2,833 | 1,650 | 1,185 |
| 4 | 0,023 | 0,145 | 0,122 | 0,085 | 0,052 | 0,206 |
| 5 | 0,618 | 0,000 | 0,203 | 0,666 | 0,182 | 0,265 |
| | MIN (AB) | | | | | |
| 1 | 2,038 | 0,925 | 1,980 | 1,900 | 1,800 | 1,175 |
| 2 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 3 | 0,290 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 4 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| 5 | 0,106 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |

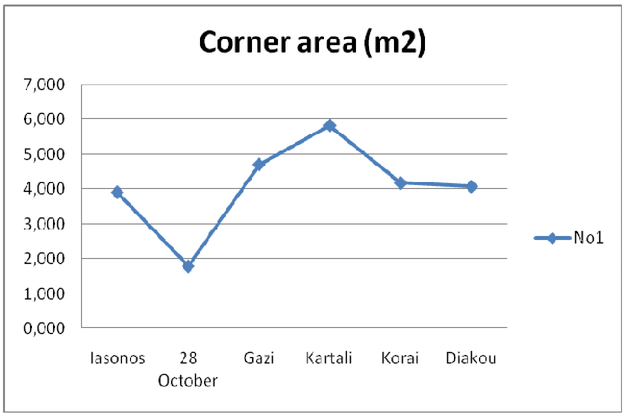


Fig.11: Corner indicator No1

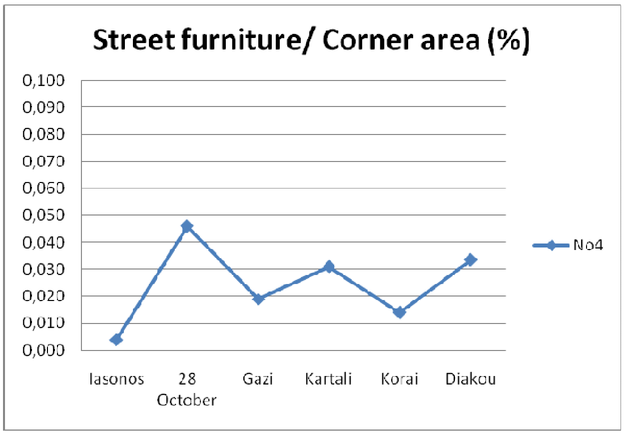


Fig.12: Corner indicator No4

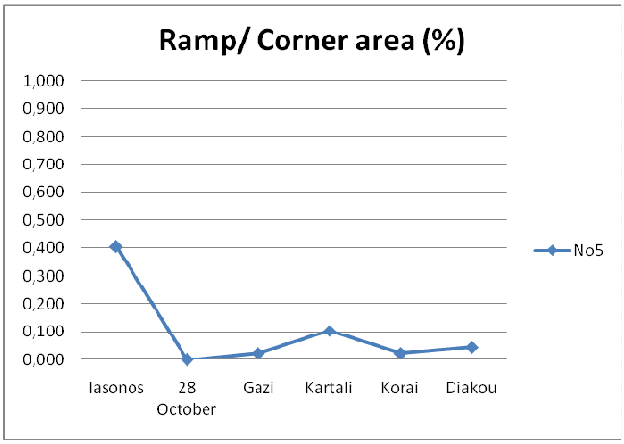


Fig.13: Corner indicator No5

### 3.4 Crosswalk indicators

The results from the implementation of the crosswalk indicators are presented in Table 10. We present the average rate of each indicator and the maximum and minimum rates of the crosswalks of both road segments across the streets. There were three types of crosswalks: typical, traffic calming and pedestrian roads. In the last case the crosswalk area did not exist but we considered it as the continuous of the pedestrian desire route. As the crosswalk width we considered the average width of the nearby sidewalks (before and after the crosswalk).

The indicator No3 describes the average crosswalk area of the streets according to their length (No1) and width (No2), (Fig.14). The highest rate of the crosswalk area was noticed in Iasonos St ($21.58m^2$) and Kartali St ($20.34m^2$). The lowest rate of the crosswalk area was noticed in Diakou St ($8.34m^2$). This indicator describes the major differences between the crosswalk area across main urban streets and the collector or local streets due to the presence of wider sidewalks. The basic concept of the crosswalk area if it was not designated was the consideration of the pedestrian desire route.

Table 10: Crosswalk indicators

| Indicators | Iasonos | 28 October | Gazi | Kartali | Korai | Diakou |
|---|---|---|---|---|---|---|
| | AVERAGE (AB) | | | | | |
| 1 | 6,64 | 6,22 | 5,92 | 6,77 | 6,09 | 5,38 |
| 2 | 3,13 | 1,56 | 2,07 | 2,96 | 1,65 | 1,56 |
| 3 | 21,58 | 10,26 | 12,20 | 20,34 | 9,85 | 8,34 |
| | MAX (AB) | | | | | |
| 1 | 10,25 | 9,50 | 8,00 | 9,50 | 11,00 | 7,00 |
| 2 | 4,50 | 4,50 | 2,20 | 3,75 | 2,00 | 2,00 |
| 3 | 43,43 | 42,75 | 16,50 | 34,50 | 16,50 | 12,50 |
| | MIN (AB) | | | | | |
| 1 | 3,58 | 2,90 | 4,50 | 3,50 | 3,00 | 3,00 |
| 2 | 1,70 | 1,00 | 1,60 | 2,20 | 1,35 | 0,80 |
| 3 | 9,80 | 4,34 | 8,75 | 7,70 | 5,70 | 4,00 |

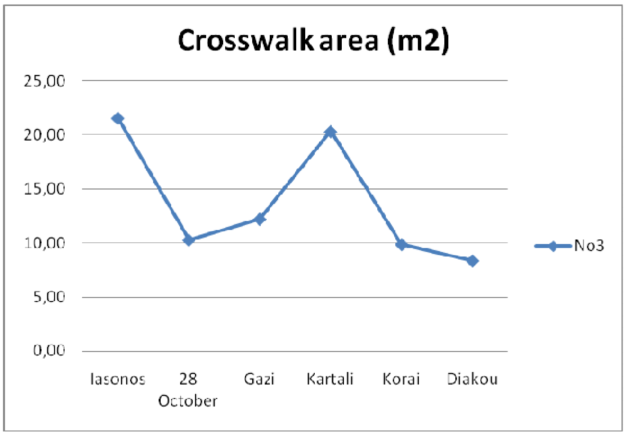


Fig.14: Crosswalk indicator No3

## 4 Conclusions

This study implemented a group of indicators in order to evaluate the walkability features of the pedestrian infrastructure across urban streets. The indicators were split into three categories: road segment, corner and crosswalk indicators. Some of the most important results of our study are the following:

- Their counting can be achieved only after a topographic charting of the pedestrian infrastructure.
- The presence of street furniture is critical for the pedestrians and motorists.
- Street furniture should be located separately of the pedestrian desire route.
- Pedestrians need a clear and unobstructed route across their desire line from sidewalks to corners and crosswalks.

- The width of the pedestrian route was about 55% of the constructed sidewalk width.
- The presence of bus stop shelters and kiosks create “low walkability sites” and “pedestrian black spots”.
- The presence of ramps in street corners raises the walking convenience, safety and visibility among road users.
- If no designated crosswalks are presented then the pedestrian desire route should be considered as one.

The results of this study can help engineers to design and construct pedestrian infrastructure reaching a high walkability level. Furthermore, the proposed indicators can be included in a pedestrian safety audit project targeting at focused remedial actions to improve the pedestrian infrastructure under the framework of sustainability.

*References:*

[1] Project on Environmentally Sustainable Transport, Organization for Economical Cooperation and Development (OECD), 1996

[2] Defining Sustainable Transport, Center for Sustainable Transport (CST), 2005, www.cst.uwinnipeg.ca.documents

[3] Hart M., Guide to Sustainable Community Indicators (second edition), Sustainable Measures, West Hartford, CT, 2006, www.sustainablemeasures.com

[4] Gilbert, R., Irwin, N., Hollingworth, B., and Blais, P., Sustainable Transportation Performance Indicators (STPI), Center for Sustainable Transportation, www.richardgilbert.ca

[5] Samuel, P., and Litman, T., Optimal Level of Automobile Dependency (A TQ Point/Counterpoint Exchange), *Transportation Quarterly*, Vol. 55, Issue 1, 2001, pp. 5-32

[6] Litman, T., Socially Optimal Transport Prices and Market: Principles, Strategies and Impacts, Victoria Transport Policy Institute (VTPI), 2009

[7] Litman, T., Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications, Victoria Transport Policy Institute (VTPI), 2009

[8] Indicators of Sustainable Community: Sustainable Seattle and Indicators, 2004, www.sustainableseattle.org

[9] Kenworthy, J., and Newman, P., *Sustainability and Cities: Overcoming Automobile Dependence*, Island Press, Washington DC, 1999

[10] Spiekermann K., and Wegener, M., Modelling Urban Sustainability, *International Journal of urban Sciences*, Vol. 7, Issue 1, 2003, pp. 47-64

[11] Tsouchlaraki, A., Achilleos, G., Nasioula, Z., and Nikolidakis, A., A System for Monitoring Environmental Quality of Urban Road Network and for Supporting Decision Makers, *WSEAS Transactions on Environment and Development*, Vol. 6, Issue 3, 2010, pp. 208-224

[12] Popescu, M.C., and Mastorakis, N., Aspects Regarding the Use of Renewable Energy in EU Countries, *WSEAS Transactions on Environment and Development*, Vol. 6, Issue 4, 2010, pp. 265-275

[13] Kralj, D., and Markic, M., Processes Innovation and Sustainable Development, *WSEAS Transactions on Environment and Development*, Vol. 4, Issue 2, 2008, pp. 99-108

[14] Bata, R., Obrsalova, I., and Costa-Jordao C., Comparison of sustainable environment indicators aggregation possibilities by means of chosen Petri nets species, WSEAS Transactions on Environment and Development, Vol. 6, Issue 3, 2010, pp. 166-175

[15] Ball, K., Bauman, A., Leslie, E., and Owen, N., Perceived environmental aesthetics and convenience and company are associated with walking for exercise among Australia adults, *Preventive Medicine*, 33 (5), 2001, pp. 434-440

[16] Hoehner, C.M., Brennan Ramirez, L.K., Elliott, M.B., Handy, S.L., and Brownson, R.C., Perceived and objective environmental measures and physical activity among urban adults, American Journal of Preventive Medicine, 28 (2), 2005, pp. 105-116

[17] Powell, K.E., Martin L.M., and Chowdhury, P.P., Places to work: Convenience and regular physical activity, *American Journal of Public Health*, 93 (9), 2003, pp. 1519-1521

[18] Cervero, R., and Duncan, M., Walking, bicycling and urban landscapes: Evidence from the San Francisco Bay Area, *American Journal of Public Health*, 93 (9), 2003, pp. 1478-1483

[19] Craig, C.L., Brownson, R.C., Cragg, S.E., and Dunn, A.L., Exploring the effect of the environment on physical activity: A study examining walking to work, *American Journal of Preventive Medicine*, 23 (2S), pp. 36-43

[20] Jacobsen, P.L., Safety in numbers: More walkers and bicyclist, safer walking and bicycling, *Injury Prevention*, 9, 2003, pp.205-209