Civil Engineering and Architecture 10(7): 2866-2876, 2022 http://www.hrpub.org
DOI: 10.13189/cea.2022.100707

# Evaluation of Walking as Sustainable Transport and Energy Generator - Case Study: Barranquilla, Colombia

**Adriana Mattos-Rodríguez[1,*], Miguel Figueroa[1], Otto Mora[1], Javier Carpintero[1], Leydis Villadiego-Rojas[1], Andrea Carolina Rodríguez Fernández[2], Jorge Barreto Jiménez[1], Marlon Parada De la Cruz[1]**

[1]Department of Civil and Environmental Engineering, Universidad de la Costa, Calle 58 # 55-66, Barranquilla, Colombia
[2]Faculty of Law, Carretera Troncal del Caribe – Sector Mamatoco, Universidad Cooperativa de Colombia, Santa Marta, Colombia

*Received August 1, 2022; Revised September 2, 2022; Accepted October 23, 2022*

***Cite This Paper in the Following Citation Styles***

***(a):** [1] Adriana Mattos-Rodríguez, Miguel Figueroa, Otto Mora, Javier Carpintero, Leydis Villadiego-Rojas, Andrea Carolina Rodríguez Fernández, Jorge Barreto Jiménez, Marlon Parada De la Cruz , "Evaluation of Walking as Sustainable Transport and Energy Generator - Case Study: Barranquilla, Colombia," Civil Engineering and Architecture, Vol. 10, No. 7, pp. 2866 - 2876, 2022. DOI: 10.13189/cea.2022.100707.*

***(b):** Adriana Mattos-Rodríguez, Miguel Figueroa, Otto Mora, Javier Carpintero, Leydis Villadiego-Rojas, Andrea Carolina Rodríguez Fernández, Jorge Barreto Jiménez, Marlon Parada De la Cruz (2022). Evaluation of Walking as Sustainable Transport and Energy Generator - Case Study: Barranquilla, Colombia. Civil Engineering and Architecture, 10(7), 2866 - 2876. DOI: 10.13189/cea.2022.100707.*



**Abstract** Pedestrian traffic in public space is associated with a level of service (LOS) that qualitatively describes the operating conditions according to the spaces available in square meters per pedestrian. Daily, people need to travel to their workplaces, schools, and universities, or to carry out any other activity using means of transportation such as walking, bicycle, car, or public transport, among others. In many cases, at least one walkable path is required regardless of the type of transport means selected to make a trip according to its accessibility. This article presents the analysis of piezoelectric power generation on the main street in the city of Barranquilla, Atlántico (Colombia), considering the pedestrian volume and the level of service of the sidewalks, according to the geometry of the road an energy consumption is estimated, then this data is compared with pedestrian accessibility indices (walkability index) of the city, with the aim of defining the functionality and applicability of the measure for the generation of energy from innovative and environmentally friendly sources. The results show that the city requires substantial modifications to make it more walkable, promoting active transportation and the inclusion of piezoelectric power generation strategies is an option to make a public space potentially sustainable.

**Keywords** Piezoelectric Power, Level of Service, Walkability Index, Sustainable Transport

## 1. Introduction

About 55% of the world's population is located in cities [1] and according to the United Nations [2], these cities consume a large part of the energy supply and generate about 70% of greenhouse gas emissions. Life in big cities implies that people make a considerable number of trips involving an origin and a destination, making use of different modes of transportation, some of which generate a larger carbon footprint than others. Regardless of the mode of transport chosen by people when making a trip, walking is necessary to complete any trip. Additionally, it is not exclusive to transportation modes, as there are many other reasons why people do it, such as a physical activity that contributes to health, facilitates a social encounter, enjoyment of public space, appreciation of the landscape, walking pets, among others [3,4].

Walking is important for daily life and therefore the functionality of some elements of public space and road infrastructure prove to be of great relevance, since they influence the operating conditions of pedestrian traffic and the experiences perceived by pedestrians when making a trip. To ensure an adequate level of operation and road safety, the implementation of devices such as traffic lights, public lighting, and advertising signs, among others, may be necessary, but at the same time, they generate energy consumption whose origin is linked to the burning of fossil fuels and, therefore, their operation is associated with carbon footprints as a result of combustion processes.

In response to these problems, renewable energies have positioned themselves as feasible alternatives for energy generation within the process of independence from fossil fuels due to their virtually inexhaustible sources and the little or no environmental impact they generate. One of these sources mentioned is piezoelectric energy together with energy harvesting processes designed to collect the energy available in the environment, usually "wasted", to later transform it into electrical energy. A part of this unused potential comes from the footsteps resulting from the action of walking. Promoting walking as a sustainable mode of transport has several benefits, some immediate in health, others in the medium and long term with the reduction of emissions, improving the quality of the air we breathe, therefore, making the city more walkable and taking advantage of the energy generated, promotes sustainability and improves the quality of life.

## 2. Problematic and Literature Overview

In the public space, one of the most important infrastructure elements is the sidewalks, which are intended for the permanence and circulation of pedestrians. Like roads, depending on their infrastructure characteristics, these can be classified according to their level of service, understood as the qualitative description of the traffic conditions on the pedestrian infrastructure.

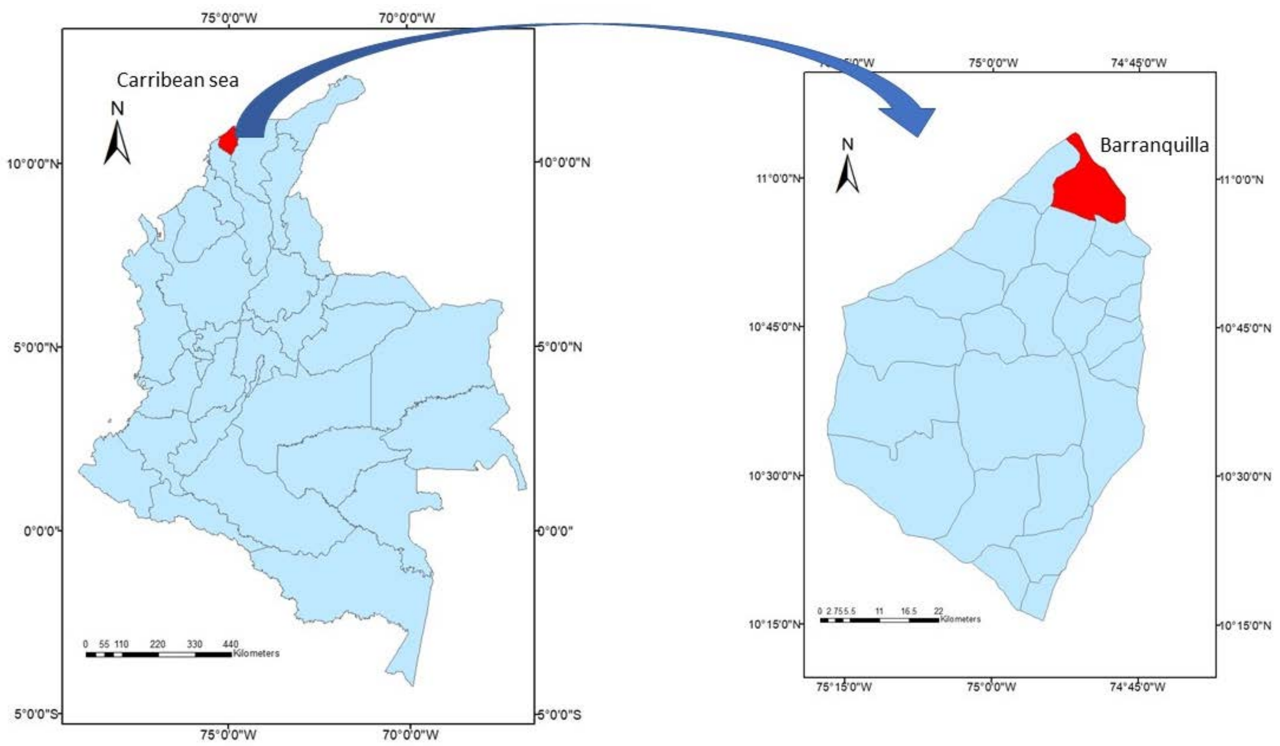


**Figure 1.** Localization of the City of Barranquilla (Atlántico) in Colombia

**Figure 2.** Pedestrian traffic in the Historic Center of Barranquilla [5]

Within the city of Barranquilla, which is located in the department of Atlántico in Colombia (Figure 1), there are areas with high pedestrian traffic. Only in the Historic Center area, there is a peak data record of 5500 pedestrians per hour between 8:15 am and 9:15 am (Figure 2). Other areas with high pedestrian traffic that can be considered as they are places that generate a large gathering of people are universities, shopping malls, mass transport stations or recreational areas (Figure 3).

Cities are the primary sources of $CO_2$ emission, coming with energy consumption as the most significant source [7].

Recently a group of non-conventional renewable energies has awakened an interest to solve the growing energy demand. One of these is vibration-based energy harvesting which is known as piezoelectric energy. The principle involves capturing residual energy from the environment and then converting it into electricity by principles of solid mechanics such as deformation energy.

**Figure 3.** Gran Malecón del Río pedestrian traffic. [6]

Taking into account that there are proven technologies in the market to take the energy generated by the pedestrian flow through the installation of piezoelectric tiles in areas of high pedestrian traffic, the purpose of this research is to estimate the potential of electricity generation by piezoelectric effect through the pedestrian mobility of the community, basing the study in a strategic area of the city such as 85th Street, which will be subject to the level of serviceability of the sidewalks.

### 2.1. Energy

The concept of energy is not a straightforward subject, according to Tippens [8] energy can be considered as something that can be converted into work. By saying that an object possesses energy, it means that it is capable of exerting a force on another object to do work on it. Conversely, if work is done on an object, this has been provided with an amount of energy equal to the work done. At the same time, distinguishes between two types of energy of great interest for mechanics:

- Kinetic energy, understood as the energy a body has by virtue of its motion.
- Potential energy, understood as the energy a system has by virtue of its position or condition.

It is said that all mass (m) that has velocity (v) also possesses kinetic energy. However, for there to be potential energy it is necessary to have the potential of an applied force. Therefore, an object itself cannot have potential energy; rather, the latter must belong to the system.

To Young and Freedman [9], the concept of energy arises from the principle of conservation of energy: energy is a quantity that can be converted from one form to another, but cannot be created or destroyed. Michinel and D'Alessandro Martínez [10], state that energy is a physical quantity that can present itself in various forms and give rise to transformation processes. However, energy can also adopt the concept of physical property or magnitude that can be transformed or transmitted and that intervenes in the processes of changes of state.

### 2.2. Piezoelectric Effect and Energy Harvesting

Under the approach of Erturk and Inman [11], when talking about energy harvesting, reference is made to technologies that harness wasted energy from the environment to provide remote sources of electrical power and/or recharge storage devices such as batteries and capacitors.

Piezoelectricity, according to Jung, Lee, Baek, Jung, Yoon & Kang [12] can be understood as a strong link between both mechanical and electrical behavior of some types of ceramics and crystals. The piezoelectric effect, which is typically classified as direct or opposing, is exhibited in these kinds of materials. Therefore, whenever a piezoelectric material is put under mechanical stress, it responds to it with an electrical polarization that is proportional to such stress, this is known as a direct piezoelectric effect. Likewise, when that same material is exposed to an electrical polarization, the material shows an amount of stress proportional to the polarization field, this is known as the opposite piezoelectric effect.

According to Gutierrez [12], piezoelectricity is the general term describing the property exhibited by some crystals (crystal lattices) to become electrically polarized when a voltage, either compressive or extensive, is applied. Quartz is a good example of piezoelectric material. If compressive stress is applied to the crystal, it will develop an electric moment proportional to the applied force (direct piezoelectric effect).

Recently, Wang, Wang, Yu, & Gao [14] studied the performance of piezoelectric energy collectors, proposing the use of collectors with elastic extensions to tune and increase their productivity and obtain positive results, supported mathematical models and numerical simulations.

### 2.3. Renewable Energies

According to Merino [14], among the different energy sources, renewable energy sources are those that are produced continuously. All renewable energy sources (except tidal and geothermal) ultimately come from the sun.

Its energy causes the differences in atmospheric pressure that originate from the winds, the source of wind energy. It also causes the evaporation of water, which then precipitates to form rivers, which provide hydroelectric power. Plants and algae use the sun for photosynthesis, the source of all organic matter (or biomass) on Earth. Lastly, the sun is used directly as solar energy, both as thermal and photovoltaic energy.

These sources are inexhaustible on a human scale, although in the case of biomass, this is true as long as natural cycles are respected.

Energy from solar, biological, and geophysical origins can be defined as Renewable Energy that is created o restored by natural processes. The behavior of the environment presents cyclic flows of energy which contribute to the generation of this (Renewable Energy) [15].

According to Cuidemos el Planeta [16] renewable energies are those obtained from natural sources that produce energy inexhaustibly and indefinitely. They are also considered renewable when they are obtained from sources that regenerate naturally over time, such as the forest mass.

### 2.4. Level of Services (LOS)

According to the National Research Council [17] quality of service requires a quantitative measure to characterize the operational conditions within a flow, whether pedestrian or vehicular. Level of service (LOS) is the qualitative measure that describes traffic conditions, generally, in terms of speed and travel time, freedom to maneuver, interruptions, comfort, and convenience.

Six levels of service are defined (Table 1) for each traffic condition. Each level is assigned a letter, representing operating conditions, being A better and F worst. Pedestrians' perception is having into account to classify those LOS. Safety is not considered.

**Table 1.** Classification of service levels [17]

| LOS | Space ($m^2$/p) |
|---|---|
| A | > 5.6 |
| B | > 3.7-5.4 |
| C | >2.2.-3.7 |
| D | >1.4-.2.2 |
| E | >0.75-1.4 |
| F | ≤0.75 |

### 2.5. Walkability Index

According to Agampatian [18], the characteristics of the built environment may condition people's decision to walk. Therefore, measurable features can help determine the extent to which the built environment affects people. Composite measures involving several environmental variables, also known as accessibility rates, are one method of measuring the degree to which an area offers opportunities to walk to various destinations or also to walk for pleasure, exercise or recreation, to access services, and even to commute to work [19].

### 2.6. Sustainable Transportation

According to the High-level Advisory Group on Sustainable Transport [20], sustainable transport is the provision of transport infrastructure services for the mobility of people and goods, promoting the socioeconomic development of current and future generations, making mobility safe, affordable, accessible, efficient and resilient, minimizing externalities that affect the environment. As established in target 11.2 of Sustainable Development Goal 11 by the United Nations [21] is a priority to provide a transport system that is safe, accessible, affordable and sustainable, by the year 2030; in conjunction with other SDGs, prioritizing actions that promote the shift to sustainable modes of transport is a necessity. Encouraging active transport (walking and cycling) is one of the main elements in the transition to sustainable mobility in urban areas [22].

## 3. Methodology

Initially, a review of the state of the art was carried out in order to obtain relevant information about piezoelectric energy, such as its concept, and piezoelectric materials, as well as references and statistics of places where this energy production option has been implemented.

In order to establish the levels of service of the sidewalks along the study section, multiple measurement days were carried out with the aim of recording the geometric dimensions of these; with the help of flexometers and a decameter type measuring tape, the widths and lengths of the pedestrian paths of 85th street in the city of Barranquilla were obtained, in addition to the areas occupied by those elements that may result in alterations of pedestrian flows, as well as a one-hour pedestrian count per section.

The estimation process of the number of steps present in each level of service of the previous analysis was estimated considering the cadence and then with that amount and the average weight of a person, by using equations the energy potential produced in each level studied was calculated. Subsequently, the total energy produced at each level of service of all sections of the analyzed street was estimated, to make an approximate the total amount of energy capacity in the corridor, and from this, the energy production capacity was also related to a reduction in $CO_2$ emissions, additionally, a projected annual consumption of the corridor was estimated considering average values of illuminance and consumption in square meters according to the installed power.

Finally, existing studies of the accessibility indexes in the city were verified to identify if the city is really walkable and if eventual improvements are required to encourage walking and if it is feasible to propose this alternative as a sustainable solution for public space.

# 4. Results

## 4.1. Levels of Service and Energetic Potential

From the field measurements taken in the study section, which was divided into sections limited by the avenues that intersect 85th Street in the city of Barranquilla, the geometric dimensions of the platforms were obtained, as well as the pedestrian flow on the sides of each avenue (Left Side, Right Side), from which the levels of service of the section under study were specified (Table 2).

Then, based on the calculated area, the number of pedestrians and the level of service, the density of pedestrians per square meter associated with each level of service was calculated (Table 3).

Following the calculations, based on the pedestrian density and service levels, an average density associated with each level was determined, and taking into account the average speed (1.1 m/s), cadence (1.91 steps/s) and the average weight of Colombian pedestrians (70.35 kg), an energy associated with the service level of this particular road was estimated, to subsequently determine the energy potential of the entire road itself for each hour (H) (Table 4).

**Table 2.** Dimensions, pedestrian flows and operating conditions of 85th Street sidewalks

| Section | Pd L | Pd R | Length (m) | Width L (m) | Width R (m) | LOS L | LOS R |
|---|---|---|---|---|---|---|---|
| 1 | 272,00 | 198,00 | 72,00 | 1,09 | 1,26 | **F** | **F** |
| 2 | 74,00 | 97,00 | 85,00 | 1,39 | 1,97 | **D** | **E** |
| 3 | 15,00 | 13,00 | 77,00 | 1,11 | 1,36 | **A** | **A** |
| 4 | 25,00 | 17,00 | 87,00 | 1,37 | 4,60 | **B** | **A** |
| 5 | 31,00 | 23,00 | 85,00 | 1,26 | 4,00 | **C** | **B** |
| 6 | 27,00 | 21,00 | 84,00 | 1,08 | 1,19 | **C** | **B** |
| 7 | 36,00 | 40,00 | 140,00 | 1,35 | 1,37 | **B** | **B** |
| 8 | 78,00 | 50,00 | 90,00 | 1,54 | 3,83 | **D** | **C** |
| 9 | 64,00 | 100,00 | 110,00 | 1,31 | 1,20 | **C** | **D** |
| 10 | 91,00 | 83,00 | 110,00 | 1,90 | 2,03 | **C** | **C** |
| 11 | 69,00 | 97,00 | 84,00 | 1,24 | 1,22 | **D** | **E** |
| 12 | 56,00 | 51,00 | 84,00 | 1,20 | 1,23 | **D** | **D** |
| 13 | 28,00 | 44,00 | 91,00 | 3,51 | 1,25 | **A** | **A** |
| 14 | 36,00 | 114,00 | 92,00 | 1,25 | 1,24 | **C** | **E** |
| 15 | 16,00 | 68,00 | 270,00 | 1,29 | 1,57 | **A** | **B** |
| 16 | 33,00 | 32,00 | 220,00 | 0,80 | 1,26 | **B** | **B** |

Where:

Pd: Pedestrian

L = Left

R = Right

LOS = Level of Service

**Table 3.** Density of pedestrians per area in each section of the street 85

| Section | LOS L | LOS R | Left Area ($m^2$) | Right Area ($m^2$) | Density Left (Pd /$m^2$) | Density Right (Pd /$m^2$) |
|---|---|---|---|---|---|---|
| 1 | **F** | **F** | 78,48 | 90,72 | 3,47 | 2,18 |
| 2 | **D** | **E** | 118,15 | 167,45 | 0,63 | 0,58 |
| 3 | **A** | **A** | 85,47 | 104,72 | 0,18 | 0,12 |
| 4 | **B** | **A** | 119,19 | 400,20 | 0,21 | 0,04 |
| 5 | **C** | **B** | 107,10 | 340,00 | 0,29 | 0,07 |
| 6 | **C** | **B** | 90,72 | 99,96 | 0,30 | 0,21 |
| 7 | **B** | **B** | 189,00 | 191,80 | 0,19 | 0,21 |
| 8 | **D** | **C** | 138,60 | 344,70 | 0,56 | 0,15 |
| 9 | **C** | **D** | 144,10 | 132,00 | 0,44 | 0,76 |
| 10 | **C** | **C** | 209,00 | 223,30 | 0,44 | 0,37 |
| 11 | **D** | **E** | 104,16 | 102,48 | 0,66 | 0,95 |
| 12 | **D** | **D** | 100,80 | 103,32 | 0,56 | 0,49 |
| 13 | **A** | **A** | 319,41 | 113,75 | 0,09 | 0,39 |
| 14 | **C** | **E** | 115,00 | 114,08 | 0,31 | 1,00 |
| 15 | **A** | **B** | 348,30 | 423,90 | 0,05 | 0,16 |
| 16 | **B** | **B** | 176,00 | 277,20 | 0,19 | 0,12 |

**Table 4.** Energy potential according to LOS and total potential for the 85th street, both in kWh/H

| LOS | AVG density (Pd /$m^2$) | T (s) | Steps | E (J/LOS) | E LOS (kWh) | E LOS (kWh/H) | E (kWhVia)/(H) |
|---|---|---|---|---|---|---|---|
| **F** | 2,82 | 2,57 | 4,90 | 44,00 | 1,2E-05 | 4,4E-02 | 7,44 |
| **E** | 0,84 | 0,77 | 1,46 | 13,11 | 3,6E-06 | 1,3E-02 | 4,04 |
| **D** | 0,61 | 0,55 | 1,06 | 9,50 | 2,6E-06 | 9,5E-03 | 6,62 |
| **C** | 0,33 | 0,30 | 0,57 | 5,11 | 1,4E-06 | 5,1E-03 | 6,31 |
| **B** | 0,17 | 0,15 | 0,29 | 2,63 | 7,3E-07 | 2,6E-03 | 4,78 |
| **A** | 0,14 | 0,13 | 0,25 | 2,24 | 6,2E-07 | 2,2E-03 | 3,07 |
| | | | | | | **Total** | **32,26** |

Where:

AVG: Average

E: Energy

T: Time

## 4.2. Energy, Reduction of $CO_2$ and Consumption

As in the initial calculations, only the hourly energy potential of the road was estimated, we will proceed to consider that the occupancy of the road can be similar in a time slot of the day with a periodicity of five days a week. Considering then an average pedestrian density in 4 hours a day for 5 days a week (Considering a similar flow in the hours of 8:00-9:00, 12:00-13:00, 14:00-15:00 and 18:00-19:00), during the 52 weeks of the year, the annual energy potential of the road is:

$$32{,}26x4x5x52 = 33550{,}4kWh \quad (1)$$

The calculation of the carbon dioxide reduction associated with this energy production is made by taking as a reference the emission factor of $CO_2$, which for electric power is 0,16438 $KgCO_2$ eq/Kwh.

$$Reduction\ CO_2 = \frac{Energy\ produced\ [kWh]}{year} * (0{,}16438\ kgCO\_2\ eq)/kWh \quad (2)$$

Therefore, the $CO_2$ reduction of the roadway is:

$$Reduction\ CO_2 = 33550{,}4\ kWh/year * (0{,}16438\ kgCO\_2\ eq)/kWh = 5515{,}01\ kgCO\_2\ eq \quad (3)$$

The energy consumption in terms of street lighting of a road will depend on the size of the road, not only considering the width of the sidewalks, but also the width of the vehicular roadway. These geometrical data will be important in the lighting design, as well as the normative stipulations that regulate the illuminance required in the spaces, from these it will be possible to calculate the installed power that is required to guarantee an optimal design, in terms of energy efficiency.

As stipulated by Calvo González [23], in the lighting calculations for a lighting project for the town of Parla in Madrid, the average illuminance (lx = lumen/$m^2$) for public lighting varies between 9.52 and 31 and the consumption associated with that illuminance varies between 0.126 - 0.746 Wh/$m^2$ for each hour of use.

Considering then for 85th Street, our study road, a design with an average illuminance of 20 lx with an associated consumption of 0.44 Wh/$m^2$, and the geometric data in Table 5, we can estimate a projected annual consumption of 38442.2 kWh, in which the use of 12 hours per day of the installed power is expected, in the time slot from 18:00 to 06:00.

### 4.3. Accessibility in Barranquilla

Considering that the decision to walk depends on the built environment, it is important to account for the accessibility index to verify how feasible it is to actually walk on a sidewalk and that the necessary conditions are provided for safe pedestrian transit. Arellana Guzmán [24] based on surveys conducted by Saltarín Molino [25] in the city of Barranquilla, the variables that have the greatest impact on the accessibility index are five, which are as follows:

1. Mobility of the sidewalk: in the perception of the users, the most important aspect of pedestrian mobility is that the platform is in good condition and that there are no obstacles.
2. Safety in the event of an accident: Users perceive that the most important thing when moving along a roadway is the traffic control devices.
3. Safety from robberies: The perception of users is that it is preferable to know that there are security cameras or police officers when circulating on a road.
4. Sidewalk comfort: For pedestrians, it is essential that the roads are clean and have trees.
5. Attractiveness: In the perception of pedestrians, the most attractive thing that sidewalks should have, is accessibility to public transportation and shopping areas.

Arellana Guzmán [24], determined the accessibility index of several roads in the city of Barranquilla, and classified them on a scale of 0 to 1, where 0 is the worst conditions (impassable section) and 1 is the best (Figure 3).

As can be seen in Figure 4, and according to the findings by Arellana Guzmán [24], the vast majority of the sidewalks parallel to the roads do not meet the requirements to be considered the most appropriate for walking in terms of comfort, safety and mobility, and part of those sections analyzed also have deficiencies in their structural conditions, since more than 75% have an accessibility index below 0.4.

**Table 5.** Energy potential according to LOS and total potential for 85th street, both in kWh/H

| SW (m) | RW (m) | TW (m) | L (m) | A ($m^2$) | C (Wh/m2H) | I (lx) | C (kWh/H) | AC kWh/año |
|---|---|---|---|---|---|---|---|---|
| 1,6 | 8,0 | 11,2 | 1781,0 | 19947,2 | 0,44 | 20,0 | 8,8 | 38442,2 |

Where:
SW: Sidewalk Width
RW: Road Width
TW: Total Width
L: Length
A: Area
C: Consumption
AC= Annual consumption
I= Illuminance

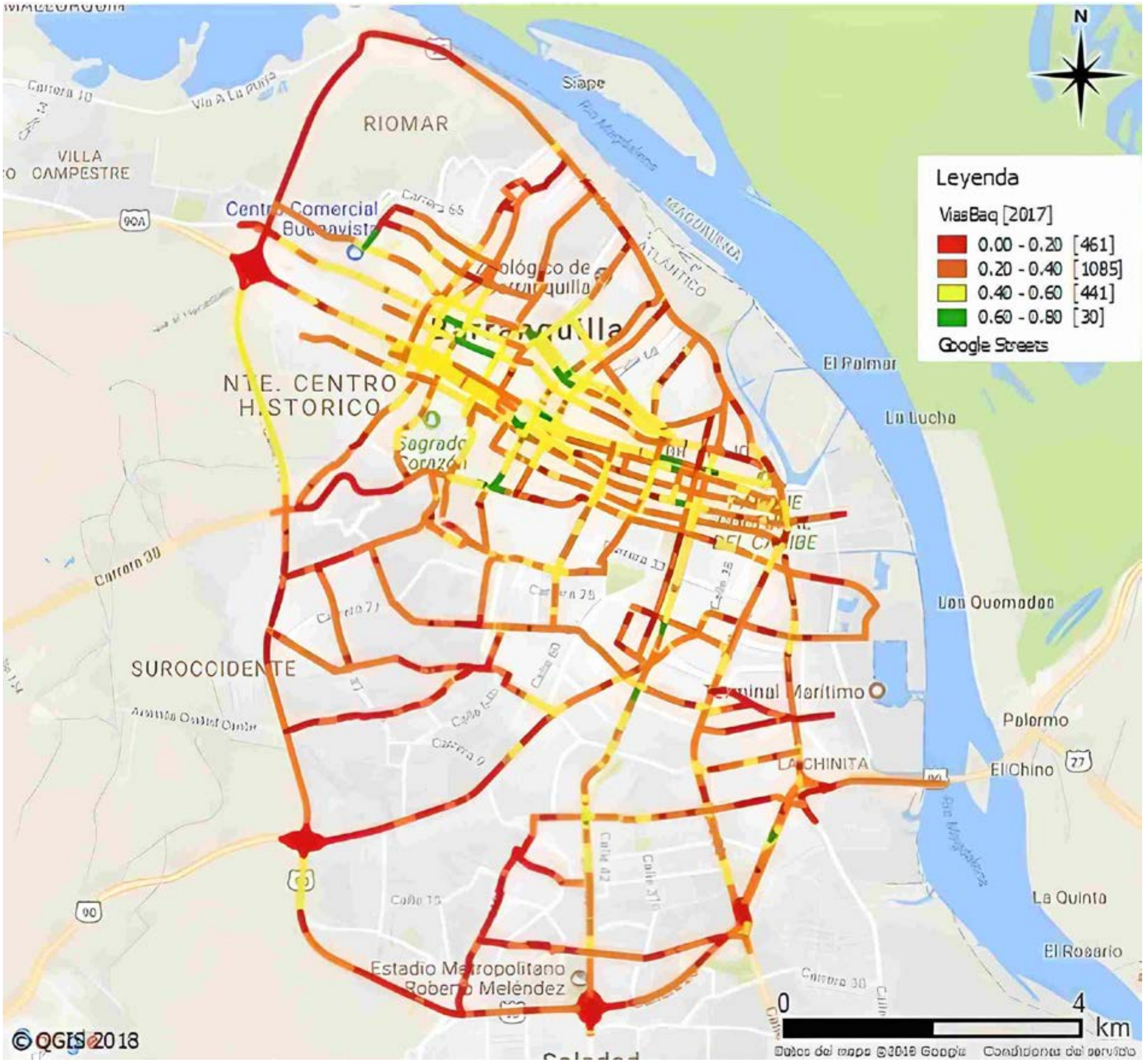


**Figure 4.** Walking accessibility index in the main roads of Barranquilla (Map elaborated in Qgis) [24]

(a) (b)

**Figure 5.** (a) and (b) Sidewalk slopes in the city of Barranquilla. [26]

Likewise, according to the information reported by El Heraldo [26], 51% of the sidewalks in the city of Barranquilla do not comply with the regulations that govern them. One of the main causes of this is the arbitrary modification of levels by homeowners or neighboring buildings (Figure 5), this unfortunate situation has existed for a long time as mentioned by the spokesman of the Office of Urban Control and Public Space. In terms of environmental sustainability, this article highlights the establishment of the Public Space Manual, which indicates that future public space is oriented by a commitment to a sustainable city and seeks to address phenomena such as global warming and the greenhouse effect.

# 5. Discussion

### 5.1. Sustainable Transportation, Walkability and Energy

Taking into account the above, it is important to note that promoting walking reduces gas emissions by promoting means of transportation other than those operated with fuel, but for there to be an effective and continuous transit of pedestrians on the sidewalks and public spaces in general, it must be walkable space. Therefore, minimum standards must be in place to ensure safe mobility.

According to the results obtained and the identification of the deficiencies that exist in the sidewalks of the city of Barranquilla, it is necessary to modify this public space to make it really walkable. The modifications that are demanded imply that these needs and requirements must be involved in the land use plans of the city in the near future, so that this public space is really oriented towards the achievement of a sustainable city, which promotes walking as a means of transportation, reducing emissions, based on walkable spaces and that in turn, in the construction considerations of these spaces, elements that take advantage of the piezoelectric potential of this transit are involved.

If we really want to take advantage of the true energetic potential of a road, it must first be attractive to pedestrians in terms of walkability, therefore, it must have a walkability index at least higher than 0.7 so that the use of walking as a means of transportation is encouraged, and the traffic along it is safe, ensuring an average level of service that contributes to generating a considerable amount of energy, making this a potentially sustainable public space. There are certain limitations in the use of the energy potential, since the pedestrian flow is not constant throughout the day, nor similar on all roads. For this reason, the reforms in these issues should be oriented to those spaces that are constantly passable over a period of time, such as approach platforms to public transportation waiting for areas, purely pedestrian roads or recreational spaces where the pedestrian flow is considerable.

### 5.2. Public Space and Walkability

Reflecting on the concept of "Sustainable Urban Mobility Plans" which initially originated in Europe, under the slogan "Planning for people", it is important to prioritize the quality of life rather than just focusing on traffic and traffic speed [20]. Therefore, the public space approach is important in this prioritization, or as mentioned by ONU HABITAT [27] there must be an immediate adaptation between the urbanistic, mobility and public space spheres, the latter is the basis of the understanding of the city and is being transformed with light measures of easy implementation that involve the citizenship.

Now, understanding the sidewalks as public spaces and in accordance with the provisions established by Dos Santos, Schmitt Caccia, Barbosa Samios, & Zoppas Ferreira [28], in “The 8 principles of sidewalks” created to understand what is essential for creating good quality sidewalks, they conclude that the principles to consider are: Adequate size, universal accessibility, safe connections, clear signage, attractive spaces, permanent safety, quality surfaces and effective drainage. These principles are of vital importance to make a sidewalk a determining factor in the decision to choose to walk, and taking into account the results of Barranquilla's walkability index, it is necessary to apply important reforms in terms of urban planning for the walkable public space.

Right now, the development plan "Soy Barranquilla 2020-2023" is underway, among the challenges has to conceive Barranquilla as a Connected City, which provides spaces and means in which people can interact, mobilize and weave human capital, one in which citizens can move and interact with each other. This can be achieved by investing in the development of roads, public space, and intra-urban mobility, among other measures aimed at connecting people with people [29].

It is not a distant thought then, that those reforms that are required to plan for people and their quality of life, involve not only those that make public space walkable by creating good quality sidewalks that promote walking and consequently improve important aspects of their health, but at the same time involve other additional elements within the design of public space, such as piezoelectric tiles that make this space a potential energy generator.

### 5.3. Sustainable Cities

By studying the relationship generated between man and the social, environmental and urban surroundings, we realize that transit, especially the walkability of people from one place to another, allows the city where they live to be alive and must have the necessary adaptations to meet the needs of mobility, according to the guidelines of sustainable development.

This shows the importance that public space represents for the life of human beings and how all physical elements must be adapted to meet the needs of mobility in the city. Hence, the national legal system contemplates normative guidelines capable of defining and regulating public space and the rights that are exercised in it. The public space contemplates a cultural and social dimension that allows processes of identification and community relations to take place, a fact that structures it as a modeling axis of the cities.

Thus, in Colombia, Decree 1504 of 1998 in Article 2 defines public space as:

"set of real estate, architectural works and infrastructure, and natural resources destined to the satisfaction of collective urban needs that transcend the limits of the individual interests of its inhabitants." [30]

Therefore, it is relevant to implement actions aimed towards achieving the development of sustainable public and urban spaces in order to protect natural resources and guarantee the right to a healthy environment.

This is intrinsically related to the concept of sustainability, especially in terms of mobility, construction of structures and management of spaces in cities, which have taken on a preponderant role in the life of human beings. Therefore, walking is instituted as an alternative means of sustainable mobility within the cities, even more so when it requires mobilization on foot, since it is necessary to have access to goods and services on a permanent basis; in addition to the fact that walking represents an important element in public health issues.

## 6. Conclusions

Public space should be oriented to people, seeking to improve their quality of life, and this general consensus is important in terms of sustainability in the future of cities. Rethinking how this space is conceived, leads us to analyze all the dynamics that are framed in it, not only in terms of circulation, but also in terms of its effective use. According to what has been studied, it is concluded that there is a need to improve it in the city of Barranquilla in order to promote its efficient use.

In terms of walkability, the data obtained are very discouraging, because despite having many roads that prioritize and optimize vehicular traffic, the sidewalks adjacent to them do not invite pedestrians to use them, since their indexes are below 0.4. Without a walkable public space, it is not possible to have a considerable flow of pedestrians circulating "comfortably" on a sidewalk, but this weakness is seen as an opportunity for improvement in the near future.

Seeing then the case of 85th Street in Barranquilla, which presents a considerable pedestrian circulation even with the difficulties of the walkability of the city and its possible energy potential according to its current pedestrian flow, it is expected that with certain improvements the transit through the same becomes more enjoyable for the user and that this flow in turn increases without compromising pedestrian comfort conditions Improving this space would not only involve encouraging active transportation (walking), but, if these reforms include elements that involve "energy harvesting" technology, it would mean taking advantage of the energy wasted by the environment. This street alone is estimated to generate approximately 33500 kWh per year if piezoelectric tiles were implemented in their entirety (in an idealized scenario), with this amount of energy it would be possible to cover part of the energy demand requested by public lighting (approximately 80-85%).

There are limitations to the applicability of this alternative related to the service levels of the sidewalks, since low flow, would imply little energy generation, therefore, it was required to make localized feasibilities according to the uses of the road sections. According to the above, the piezoelectric energy alternative would be better applicable (in a real scenario) in areas of approach to public transport stops, purely pedestrian roads (as in the case of the historic center) or public recreational spaces where circulation is constant in time slots and with levels of service that are suitable for generating useful amounts of energy, compared to the investment of the inclusion of this technology.

Finally, these alternatives could not only be applied within a local scenario, as is the city of Barranquilla, since, in the case of Colombia but there are also cities that have greater pedestrian traffic such as Medellin and Bogota, where it would be important to study this feasibility. Likewise, the promotion of sustainable transportation is being applied in most of Latin America and studying the inclusion of this type of energy generation alternatives and their eventual implementation would be something of great value in the joint purpose of achieving sustainable cities in the near future.

## REFERENCES

[1] Banco Mundial, "Desarrollo urbano: Panorama general," World Bank, 2020. Online available from: https://www.bancomundial.org/es/topic/urbandevelopment/overview.

[2] Naciones Unidas, "Las ciudades, 'causa y solución' del cambio climático," Noticias ONU, Sep. 18, 2019. Online available from:https://news.un.org/es/story/2019/09/1462322.

[3] Páramo P., Burbano A., Aguilar M., García-Anco E., Pari-Portillo E., Jiménez-Domínguez B., López-Aguilar R., Moyano-Díaz E., Viera E., Elgier A M., Rosas G., Viera J., "La experiencia de caminar en ciudades latinoamericanas," Revista de Arquitectura (Bogotá), vol. 23, no. 1, pp. 20–33, 2021, DOI: 10.14718/revarq.2021.2830.

[4] Arsandrie Y., Prakoso, A. "The Need of Pedestrian Footbridge to Promote Sustainable Living; Case Study: Footbridge Jln A Yani Pabelan, Kartasura," Civil Engineering and Architecture, vol. 8, pp. 541–548, 2020, DOI: 10.13189/cea.2020.080418.

[5] La Libertad, "Distrito se dispone a recuperar los andenes de la ciudad," Diario La Libertad - Periódico Noticioso de Colombia., Apr. 30, 2021. Online available from: https://diariolalibertad.com/sitio/2021/04/30/distrito-se-dispone-a-recuperar-los-andenes-de-la-ciudad/.

[6] Zona Cero, "El Gran Malecón del Río, la obra que marcó un antes y un después en Barranquilla," Zona Cero, 2019. Online available from:https://zonacero.com/sociales/el-gran-malecon-del-rio-la-obra-que-marco-un-antes-y-un-despues-en-barranquilla-140355.

[7] Amen M. A., "The Assessment of Cities Physical Complexity through Urban Energy Consumption," Civil Engineering and Architecture, vol. 9, no. 7, pp. 2517–2527, 2021, DOI: 10.13189/cea.2021.090735.

[8] Tippens P., Física Conceptos y Aplicaciones, 7ma ed. México: McGraw Hills, 2011.

[9] Young H. D., Freedman R. A., Física universitaria con física moderna, 12th ed., vol. 2. Pearson Educación, 2009.

[10] Michinel J., Martínez, A. "El concepto de energía en los libros de textos: de las concepciones previas a la propuesta de un nuevo sublenguaje," Enseñanza de las Ciencias: revista de investigación y experiencias didácticas; vol. 12 no. 3, 1994, DOI: 10.5565/rev/ensciencias.4424.

[11] Erturk A., Inman D. J., Piezoelectric Energy Harvesting. John Wiley & Sons, 2011.

[12] Jung W.-S., Lee M., Baek S.-H., Jung I. K., Yoon S.-J., and Kang C.-Y., "Structural approaches for enhancing output power of piezoelectric polyvinylidene fluoride generator," *Nano Energy*, vol. 22, pp. 514–523, Apr. 2016, DOI: 10.1016/j.nanoen.2016.02.043.

[13] Gutiérrez F., "Principios de Piezoelectricidad," Innovación y Experiencias Educativas, p. 11, 2010.

[14] Wang S., Wang C., Yu G., Gao Z., "Development and performance of a piezoelectric energy conversion structure applied in pavement," Energy Conversion and Management, vol. 207, no. 9, 2020, DOI: 10.1016/j.enconman.2020.112571.

[15] Merino L., "Las energías renovables," Haya Comunicación, p. 20, 2003.

[16] Instituto Interamericano de Cooperación para la Agricultura IICA, "Uso y acceso a las energías renovables en territorios rurales: mapa de ruta," 2014, Online available from: https://repositorio.iica.int/handle/11324/11565

[17] Cuidemos el planeta, "¿Qué son las energías renovables?," 2018. Online available from: https://cuidemoselplaneta.org/energias-renovables/.

[18] National Research Council (U.S.), Ed., Highway capacity manual. Washington, D.C: Transportation Research Board, National Research Council, 2000.

[19] Agampatian R., Using GIS to measure walkability : A Case study in New York City. 2014. Online available from: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-145011

[20] Leslie E., Coffee N., Frank L., Owen N., Bauman A., Hugo G., "Walkability of local communities: Using geographic information systems to objectively assess relevant environmental attributes," Health & Place, vol. 13, no. 1, pp. 111–122, 2007, DOI: 10.1016/j.healthplace.2005.11.001.

[21] High-level Advisory Group on Sustainable Transport, "Mobilizing Sustainable Transport for Develppment." 2016. Online available from:https://sustainabledevelopment.un.org/content/documents/2375Mobilizing%20Sustainable%20Transport.pdf

[22] Naciones Unidas, La Agenda 2030 y los Objetivos de Desarrollo Sostenible: una oportunidad para América Latina y el Caribe (LC/G.2681-P/Rev.3). Santiago, 2018.

[23] Banister D., "The sustainable mobility paradigm," Transport Policy, vol. 15, pp. 73–80, 2008, DOI: 10.1016/j.tranpol.2007.10.005.

[24] Calvo González S., "Proyecto de alumbrado: instalaciones eléctricas, cálculos luminotécnicos y de la eficiencia energética en la ciudad de Parla," 2015. Online available from: https://e-archivo.uc3m.es/handle/10016/23088

[25] Arellana Guzman J., "Walkability index assesment in barranquilla," Thesis, Ingeniería Civil, 2018. A Online available from: http://hdl.handle.net/11323/272

[26] Saltarín Molino M. A., "Diseño de una metodología para evaluación de accesibilidad de transporte no motorizado," 2017, Online available from: https://manglar.uninorte.edu.co/handle/10584/8960

[27] El Heraldo, "El 51% de andenes incumple la norma," 2019. Online available from: https://www.elheraldo.co/barranquilla/el-51-de-andenes-incumple-la-norma-672590 (accessed Apr. 29, 2022).

[28] ONU HABITAT, "MOVILIDAD URBANA SOSTENIBLE Y ESPACIO PÚBLICO." 2016. Online available from: https://unhabitat.org/sites/default/files/documents/2019-06/sustainable_urban_mobility_and_public_space.pdf

[29] Dos Santos P. M., Schmitt Caccia L., Barbosa Samios A. A., Zoppas Ferreira L., The 8 Principles of Sidewalks. 2019. Online available from: https://wrirosscities.org/research/publication/8-principles-sidewalks

[30] Alcaldía Distrital de Barranquilla, "Plan de Desarrollo, 'Soy Barranquilla 2020-2023.'" 2020.

[31] Presidencia de la República de Colombia, "Decreto 1504 de 1998." 1998. Online available from: https://www.minambiente.gov.co/wp-content/uploads/2021/06/Decreto-1504-de-1998-Espacio-Publico.pdf