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Safe Path: Energy Harvesting from Pedestrian Movement in Karbala- Spatial Suitability and Crowd Dynamics Towards Sustainability

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ABSTRACT

The escalating population corresponds with a rising demand for electricity. A viable alternative to address this challenge involves harnessing human kinetic energy during activities such as walking. As individuals walk, they transmit energy to the ground through impact and vibrations. This energy can be captured and converted into electrical power based on the steps taken by pedestrians. This research focuses on Karbala, a city notable for its high pedestrian density, particularly during religious ceremonies where large crowds from diverse nationalities converge in its squares and corridors. The significant congregation necessitates substantial energy for lighting, escalators, air conditioning, and other operational requirements. This study explores the untapped potential of clean and safe energy generation through kinetic energy produced by human movement. It proposes the development of an energy harvesting system that leverages an advanced understanding of pedestrian density, employing the piezoelectric tile system. The research methodology included data collection and photographing the study area during a field visit, alongside the use of geographic information systems to identify optimal paths for implementing this technology to maximize energy harvesting. The study concludes that the Continue harvesting energy for five consecutive years for the purpose of launching forecasts for the coming years and medium and long-term plans to achieve the goal of sustainable development in renewable energy.

1. INTRODUCTION

The operation of industries, enterprises, and infrastructure depends on having access to inexpensive and dependable energy. It creates employment opportunities, fosters economic growth, and improves overall living conditions. Energy access also helps bridge the digital divide, enabling access to information and connectivity, thereby enhancing social well-being and promoting inclusivity. The affordability and sustainability of energy must be the key to sustainable development. Energy plays a vital role in supporting social and economic well-being, reducing poverty, promoting a healthy lifestyle, and enhancing lifestyles. Sustainable energy management, innovative production and consumption, and manufacturing support for flexible energy infrastructure development through sustainable management of natural resources are key factors in achieving a future energy system. The UN's member states endorsed the 2030 Agenda for Sustainable Development in 2015, which sets out a comprehensive framework for addressing social, economic, and environmental challenges worldwide. There are 17 Sustainable Development Goals (SDGs) in all, covering a wide variety of interrelated topics such as gender equality, cheap and renewable energy, poverty elimination, and high-quality education. Goal 7 specifically focuses on ensuring "affordable and clean energy for all."

Beyond Goal 7: While the focus of Goal 7 is on clean, inexpensive energy, it is important to note that energy-related targets and considerations are integrated throughout the other SDGs as well [1].

These interconnected goals highlight the critical role energy plays as an enabler and accelerator of sustainable development. Addressing energy-related challenges requires cross-sectoral collaboration, policy coherence, and integrated planning to ensure progress across multiple dimensions of sustainable development. By aligning efforts across goals, we can foster synergy and create a holistic approach to meet the energy needs of people while advancing the broader objectives of sustainability.

The experimental study of pedestrian crowds has contributed significantly to our understanding of crowd dynamics, human behavior, and the design of safer and more efficient spaces. As the number of people living in cities increases, this field of study remains crucial, and the importance of crowd management and safety becomes [2]. The primary focus of these studies has been to improve the conceptual understanding of service level, the design aspects of pedestrian facilities, and planning guidelines, in addition to developing the concept of the basic level of service [3, 4]. None of these concepts adequately accounts for the self-organization effects in pedestrian crowds. Such consequences, nevertheless, may give rise to unforeseen difficulties. It became increasingly apparent as a result of the variations in pedestrian flows, as explained by Henderson's method, which postulated that pedestrian crowd behavior is comparable to that of liquids or gases [5-8].

However, because of their unique interactions (such as avoidance, slow down, and maneuvers), which do not intrinsically maintain momentum and energy, these modifications are necessary for a realistic gas kinetics theory or fluid dynamics for pedestrians. Nevertheless, it is possible to formulate a theory for practical applications that directly incorporates individual pedestrian movement and the impact of this movement on generating green energy [9].

Local interactions among individuals frequently result in self-organization and repeating local interactions in human crowds and many animal groups, supporting diverse movement patterns [10-13]. When pedestrian flows move in opposite directions, the flows automatically separate into uni-directional pathways. This phenomenon is often called the intelligent collective pattern, which increases traffic efficiency without needing external control. Through the reduction of frictional effects, local acceleration, energy consumption, and walking delays, the self-organized movement pattern improves traffic flow [14].

Functional movement patterns in human crowds, such as oscillatory flows near bottlenecks [15], corridor development [16], walking, and the establishment of social categories, have been observed on several occasions [17]. One important factor in the cause of observable traffic disturbances is the variance in walking speeds of pedestrians. Local interactions between fast and slow walkers, however, result in a worldwide disintegration of organizations, diminishing the benefits that traffic separation offers both individually and collectively. This project is a first step forward in understanding the self-organization of traffic movement in crowds, which is influenced by complex behavioral mechanisms [18].

In order to build bottom-up management methods based on a quantitative understanding of crowd behaviors, it is necessary to have techniques that effectively encourage collective behaviors in crowds. Crisis management is an approach to dealing with emergencies to control their outcomes or minimize their negative effects. Moreover, crowd management and organization pose significant challenges for officials during peak visitation seasons. The recurring problem of lost visitors, health crises, or deaths in unspecified locations necessitates solutions. Additionally, there is a need to address other types of problems, such as fire or collapse disasters and stampedes during visits. Furthermore, there is a demand for rapid communication with group supervisors and field organizers to provide instructions or guidance during these disasters [19].

Managing and monitoring crowds is considered one of management's most intricate and challenging disciplines, as it requires the convergence of various administrative entities from health, road safety, and diverse services involving multiple authorities, as in Figure 1.

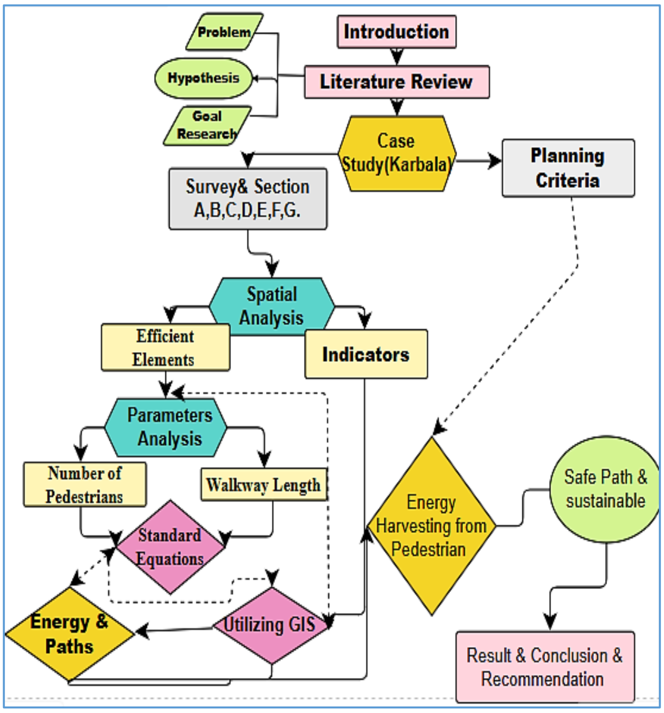


Figure 1. Methodology

2. STREET SAFETY AND SECURITY

Safety on streets and trails is an important issue that affects all members of the community. It is essential to ensure that roads are safe for all users, including pedestrians and cyclists. To achieve this goal, we can create a safer environment for all individuals to walk safely on streets and pedestrian paths. Urban designers and planners often encourage the use of aesthetic street treatments to enhance the safety of urban streets. Urban mobility strategies should also include specific measures such as better infrastructure for active mode. Doing so can promote the use of sustainable modes. So, creating safe services and infrastructure is crucial to removing barriers and restrictions on the journeys they can take [20].

3. ENERGY OF SUSTAINABLE

Sustainable energy encompasses a range of practices and technologies aimed at reducing environmental impact and promoting energy security. Here are some key points about sustainable energy [21]:

1. Renewable Energy Sources: Sustainable energy often involves using renewable sources like wind, solar, hydro, and geothermal power.
2. Energy Conservation: This involves using less energy to improve efficiency and change behaviors.
3. Energy System Transformation: Transitioning to sustainable energy requires a transformation of the current energy system to clean sources.
4. Government Policies and Finance: Achieving a sustainable energy future requires supportive government policies and adequate financing.
5. Global Efforts: The Paris Agreement and the United Nations have set targets to reduce greenhouse gas emissions and prevent global temperatures from rising more than 2 degrees Celsius above preindustrial levels.

In conclusion, sustainable energy is not just an environmental imperative but also a pathway to economic growth and social development. It is about creating a balance that allows us to thrive without depleting our planet's resources.

3.1 Energy security

Obtaining the energy required for economic expansion. The national economic implications of secure energy are covered under the Energy Security axis. It involves having access to energy sources for import, export, and transportation. Energy security guarantees that the nation's social, economic, and environmental growth is positively impacted by energy. It necessitates that nations implement more creative growth strategies. To make sure kids are aware of changes, can adjust as needed, and develop resilience to handle all the circumstances and situations they encounter [22].

3.2 Energy for better living

To provide everyone with clean energy is the aim of the energy for a better life, dependable and reasonably priced energy in order to enhance residents' quality of life. This goal includes both the capacity to pay for and the quality of physical access to electrical networks as well as a wider range of energy services. These services, which are essential for improving one's general quality of life, include transportation, heating, cooling, and power [23].

3.3 Environment and energy

The compromises involved in meeting the world's growing energy demands, preserving a clean, healthy environment, and shielding humanity from climate change are represented by the environment and energy's third pillar. Energy-related emissions account for 60% of the emission of greenhouse gases. Therefore, in order to contribute efforts to mitigate climate change, The industry sector must reduce its carbon impact throughout the entire production chain [24, 25].

(SDG-9) covers the energy sector, energy-intensive industries, energy innovation, and large-scale infrastructure. Achieving SDG9, which calls for transition, would need resilient infrastructure, sustainable energy, and resource usage, as well as the development, use, and local adaption of energy technology [23].

Achieving (Goal-11) of the Sustainable Development Goals entails developing sustainable urban energy that can support resilient infrastructure, providing cities and rural communities with sustainable energy sources, and promoting sustainable transportation [22].

Concerning energy, the most important SDGs under the "Energy for Well-being" pillar are Goal 2 on "Zero Hunger," Goals 11 and 17 are related to "Sustainable City and Societies," "Affordable and Clean Energy," and "Partnerships." SDG 2. Water and energy are involved in agriculture, and bioenergy might pose a threat to food supply, note Figure 2 [21].

This text examines the interdependence between sustainable goals and crowd organization, specifically focusing on how kinetic energy can be harnessed to generate electrical power. By strategically organizing crowd movements during visits to holy sites, it is possible to optimize the conversion of kinetic energy into electricity, thus aligning with sustainable objectives. This approach not only enhances energy efficiency but also contributes to the effective management of large groups, ensuring smoother operations at these sacred locations (Figure 3).

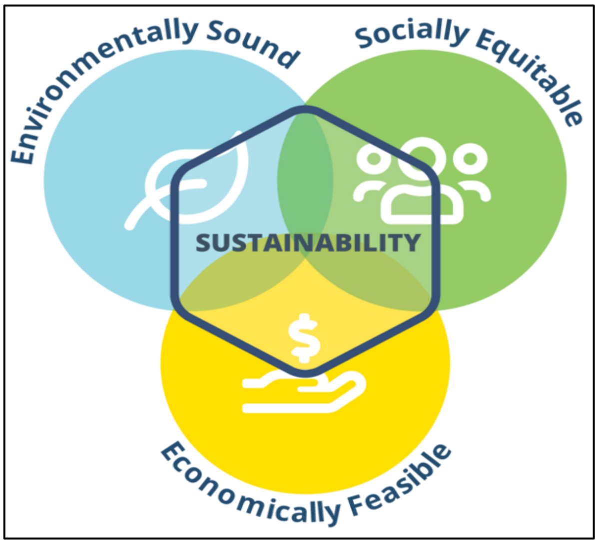


Figure 2. Pillars of sustainability

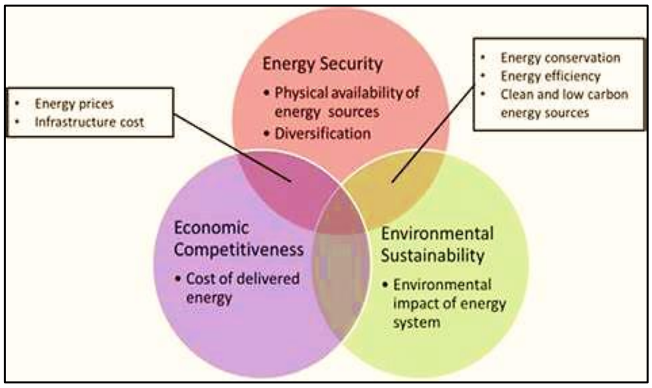


Figure 3. Connections to the SDGs

4. CROWD (VISITORS) ORGANIZATION

The term "crowd organization" refers to the study and management of large groups of people, often in public spaces or events. Here are some key points about crowd organization: [26, 27].

1. Safety and Security: Ensuring the safety of visitors or participants is a top priority.
2. Safe paths, signage, barriers, and clear instructions help guide visitors and maintain order.

4.1 Concept of crowd organization

Crowd organization refers to coordinating and effectively managing a group of people in a relatively confined space [28].

4.2 Crowd categories

Crowds can be classified based on several criteria, including: [28, 29].

- The location and boundaries of the event or occasion where the individuals gather.
- The period of the gathering.

- The purpose of the crowd gathering.
- The starting time of the gathering.
- The level of cohesion among the crowd members.
- The surrounding conditions and atmosphere of the event or occasion.

4.3 Types crowds [28]

1- Action Crowd: Also known as a common-interest crowd, such as a protest or a demonstration.
2- Political Crowd: Gathered to express political opinions or demands, these crowds are often seen in rallies and protests.
3- Religious Crowd: These are formed for spiritual purposes, such as worship services, religious festivals, or pilgrimages.
4- Emergency Crowd: This type of crowd assembles in response to an emergency or disaster.
5- Social Crowd: Social crowds gather for common daily interactions and socialization in public spaces.

5. ENERGY HARVESTING

It refers to the process by which energy is obtained from external sources, including energy (solar, thermal, wind, and kinetic energy). This energy is intersected and stored for use in small, autonomous devices such as electronic devices and wireless sensor networks. One of the researchers who has studied this topic is Michael Faraday, who discovered the basic principles of electricity generation in the nineteenth century, and his principles have been used until today [30].

6. INTELIGENT PEDESTRIAN PATH

A smart street is a fundamental piece of urban real estate. It uses data generation to maximize its capabilities, services, and value while utilizing physical infrastructure to deliver improved services to stakeholders. At the same time, it acknowledges that streets are a more atomized and, hence, more controllable unit of development overall. However, in addition to lighting, smart streets may incorporate a wide range of possible structural elements and services, such as trash management, traffic management, environmental monitoring, structural health, and space management [31].

7. ENERGY HARVESTING TILES

Electro-pressure tiles, also known as kinetic energy tiles or piezoelectric floor tiles, are an innovative technology that converts the kinetic energy from footsteps into electrical energy. This is achieved through the piezoelectric effect, where certain materials generate an electric charge in response to applied mechanical stress.

The technology not only provides a sustainable way to generate clean energy but also contributes to the interactive experience of a space. The efficiency of these tiles and their ability to contribute to a building's energy needs are subjects of ongoing research and development. At the same time, they offer a promising avenue for renewable energy; challenges such as high initial costs and the need for significant foot traffic to generate substantial power remain (Figure 4) [32].

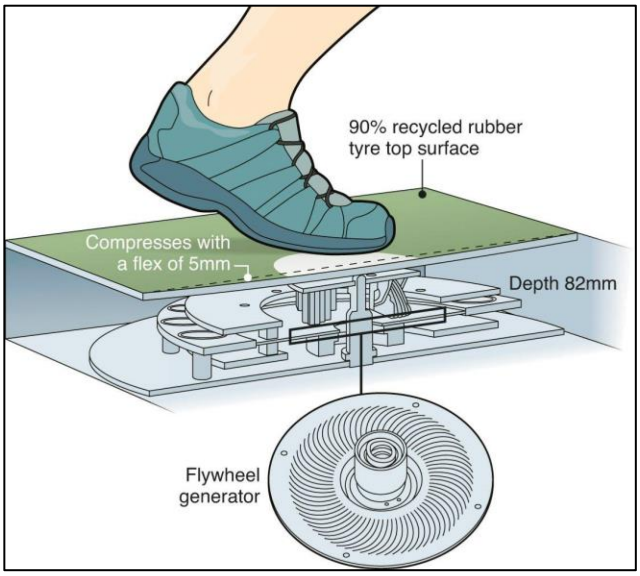


Figure 4. Energy harvesting tiles

8. PEDESTRIAN FOOTSTEPS & ENERGY OF SUSTAINABLE

Sustainable energy generation through walking is a fascinating concept that harnesses the kinetic energy produced by footsteps to generate electricity. Innovative technologies are being developed to make this a reality. The approach involves sidewalks that convert the mechanical energy from steps into electrical energy. This technology, developed by Pavegen, uses platforms within sidewalks that compress underfoot, generating energy through electromagnetic induction. Each step can produce enough energy to operate an LED bulb for 30 seconds, and the energy is stored in batteries to power lights or other devices [33].

These technologies are still in development but hold great promise for sustainable energy solutions in smart buildings and urban environments. They could potentially contribute to reducing our reliance on traditional energy sources and help in creating more sustainable cities [32].

8.1 Advantages of walking

All humans engage in the action of walking. This technique can lessen the harmful impacts on the environment while having a number of beneficial effects on health. For instance, it may generate sustainable energy from steps and lessen air pollution. One place where the majority of people utilize walking as a position to carry out any task is the university. As a result, the university may serve as a reference point for evaluating how well a feasibility study based on the potential for energy harvesting from Light Walkers is carried out [34].

8.2 Mechanism of generating electricity from footsteps

People's daily actions, including walking, can burn a lot of energy. Energy harvesting, according to, is the technique of capturing the energy present in the environment around the system and turning it into useful electrical energy. With footwork, kinetic energy may also be transformed into electrical energy [35].

Utilizing step-by-step electrical transformer devices and piezoelectric devices on sidewalks are the two methods for producing power. Energy transformation from kinetic to electrical, the devices are initially placed on pedestrian walkways. A footstep causes the plate to move lower, rotating the dynamo and producing electricity. This power can illuminate streetlights. Nevertheless, the device's effectiveness is restricted.

8.3 Potential sites for generating electricity from pedestrian walkways

As long as pressure is applied repeatedly, piezoelectric generators may be used in many locations. As an illustration, consider areas with a lot of traffic flow and gathering spots for big crowds of people. The most typical places for these situations include freeways, retail centers, pathways, train lines, and roads. On streets and highways, the volume of traffic varies throughout the day, with morning traffic being stronger than evening traffic and occasionally even all day. One example of massive power generation is a railway track, which is subjected to tremendous pressure from the trains. Piezoelectric material pads are positioned such that a higher force is permitted. A larger quantity of charge is stored at the intersection where the wheel contacts the rails and gets maximum pressure, similar to what is utilized on airport runways [36, 37].

8.4 Challenges and disadvantages of pedestrian footstep energy harvesting technology

Harvesting energy from pedestrian steps is an innovative method of generating electricity, but it comes with some drawbacks, including [38]:

1. Low energy production: The energy produced by piezoelectric materials from footsteps is relatively low. This means that a large number of steps and significant foot traffic are needed to generate a large amount of energy.
2. Complex energy conversion: The process of converting mechanical energy from footsteps into electrical energy requires rectification, maximum energy extraction, and regulation of the output voltage, which may lead to the complexity of the energy harvesting system.
3. Cost and Durability: Implementing energy harvesting technology in public spaces can be expensive. In addition, the materials and hardware used must be durable enough to withstand constant use and outdoor conditions.
4. Efficiency improvement is needed: Although progress has been made, the efficiency of the materials used for energy harvesting still needs continuous improvement to make this technology more viable.
5. Infrastructure changes: Integrating this technology into existing infrastructure requires significant changes, which can be disruptive and costly.

9. SIDEWALK

The definition of a sidewalk in relation to traffic is somewhat broad. It has a meeting point where the environment and human motions and activities meet, and they are closely related. Thus, a road, area, pedestrian walkway, or specially constructed paved pathway intended for pedestrian usage can all be considered pavement. One type of sustainable transportation system is the sidewalk. It may be a practical choice that results in good physical exercise through walking [39].

With the use of piezoelectric materials, walking energy may be captured and transformed into electrical energy. Based on observations and questionnaires, the case study reveals that 46,000 pedestrians with an average daily weight of 66.40 kg use the path. That many steps and that much weight, if the route is that long, could potentially produce 6,130 watts of electrical energy per day. Thus, using piezoelectricity is a viable method of producing power for the renewable energy-based corridor lighting system. By utilizing renewable energy sources as a clean, sustainable alternative to fossil fuels, this study helps to preserve energy from such sources. It is advisable to reference various theoretical models in order to correctly establish the operating force and account for extra relevant variables such as pedestrian speed and stride length, as the model is based on human behavior and walking processes (Table 1).

Table 1. Efficient elements to produce energy via walking footfall

Available Service	Technology	Context	Indicator	Type of Energy	Standard Equations
power consumption of the device	Piezoelectric Material Efficiency	Track length	continuity	Number of walking steps	(250.00) steps = (6.00) (s) of duration to lighting a 100.00-watt bulb (1)
Number of piezoelectric devices		Number of walkers	kinetic	foot pressure	(250 steps) / (6 s) x 1 s = 41.66 steps = 42 .00steps (2)
				foot stride length	
				walking speed	[Every (2.00 feet) of interlocking block sidewalk = 1.00 steps] (3)

10. INTERNATIONAL EXPERIENCES

10.1 Football stadium project in Rio de Janeiro, Brazil

It is the first stadium in the world to operate entirely on a renewable energy system. 200 units of tiles were installed to convert kinetic energy into electricity (Figure 5). This system has achieved success in providing electricity for 10 continuous hours [40].

10.2 Heathrow airport, London

51 tiles that convert motion energy into electricity were installed in the airport building to be illuminated by this system. This project won the Innovation Award for motion-illuminated walkways, as the number of passengers reached

18.4 million passengers in 2012, and this project helped raise awareness of sustainability, as in Figure 5 and 6 [29].

(a) (b)

Figure 5. The floor with a piezoelectric tile

Figure 6. The installation location of tiles in the airport track

10.3 The Stockholm subway station, Sweden

Energy-generating steps have been put in place at Sweden's Stockholm metro station to power the station's lights. People walking up and down the steps provide kinetic energy, which powers the stairs. The station's lighting system is then powered by the energy that has been stored in batteries. The energy-generating steps are a creative and engaging addition to the subway station in addition to offering a sustainable energy source, as in Figure 7 [41].

Figure 7. Energy-generating stairs in a Stockholm subway station

10.4 Smart walk, UAE

It converts the kinetic energy resulting from pedestrian steps into electrical energy and works with systems connected to Internet networks. It allows data to be linked via an application to phones or smart screens connected to (the walkway). It shows the number of steps, the volume of energy produced, and the number of electric cars that can be charged with the resulting energy. The "walkway" production can also be used to operate lighting poles on an expanded basis in commercial markets, sports, and hiking trails or places that witness large pedestrian traffic, as in Figure 8 [42].

Figure 8. Applying the idea of smart walking in the UAE

10.5 Mall in Johannesburg (Sandton city)

The kinetic energy of human masses is a promising source of electricity in shopping malls. It can lead to significant energy savings for lighting and door control. It has achieved high efficiency and can operate electronic locks, LED billboards, and wireless doorbells, all of which are necessary devices in shopping malls. A clean technology startup called Pavegen put in 68 movable floor tiles to spread awareness about the issues that electricity grids cause in remote areas. Other parts of South Africa are powered by the electricity that is gathered. More than two million footsteps pass through the retail center each month, consuming a substantial amount of energy and having an influence on the lives of others who only need access to basic amenities like heat and light, as in Figure 9 [43].

Figure 9. The kinetic energy generated in shopping malls

The indicators that were derived from these experiments are shown in Table 1.

11. THE PRACTICAL SIDE

11.1 Study area

The city of Karbala is located in the middle of Iraq, southwest of the city of Baghdad, at a distance of (105) km, between latitude 32 to 33N and longitude 43 to 44E. Its area is about 5.034 km². and the governorate is connected to other governorates, including Babylon, Najaf, and Qadisiyah, by many roads. The city witnessed a significant increase in urban growth as a result of the increase in population and immigration. It is watered by the Al-Husseiniyah River, which branches off from the Euphrates River and has a length of (29) km. The first tourism festival was held there, which was (Al-Ukhaydir Tourism Festival). The first on 3/3/1982. It contains many main and secondary roads and rural roads, which visitors can take to the city of Karbala. Although the majority of these roads are paved and well-suited, they are used in many cases, especially at times of religious occasions that the governorate witnesses, which leads to Visitors coming in large numbers to this governorate. Figure 10 shows the location of the study area [44].

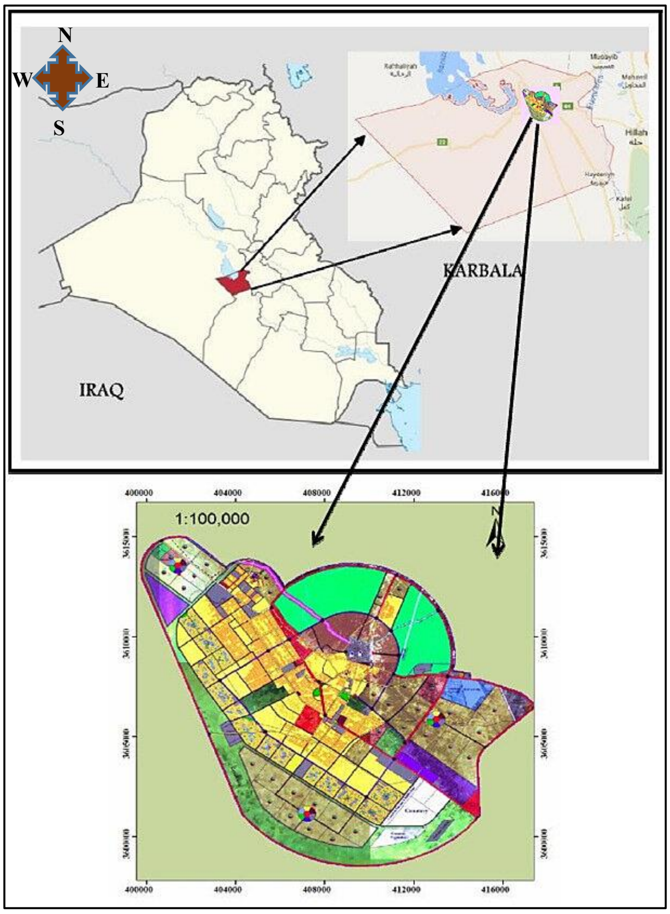


Figure 10. The location of Karbala city in Iraq

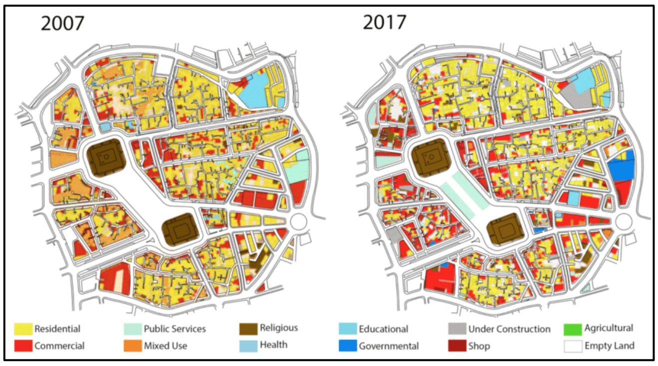
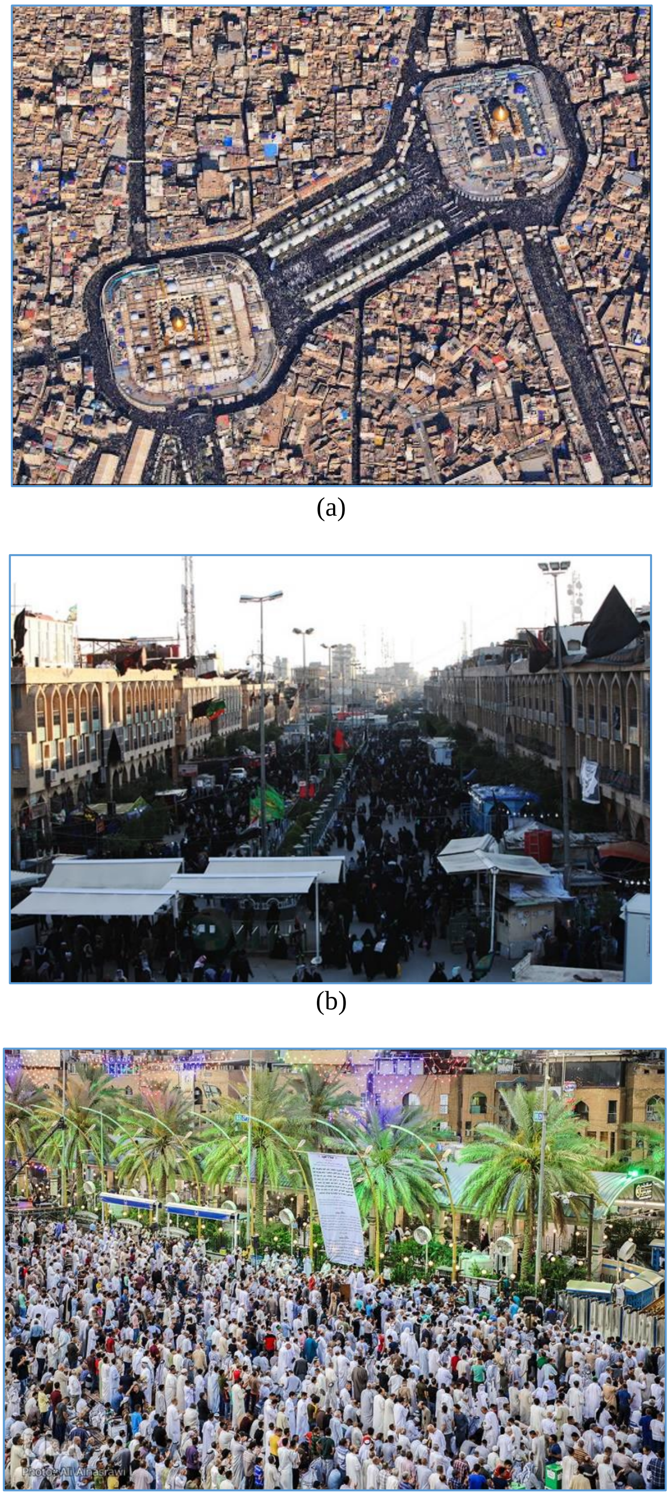


Figure 11. The development of Karbala city center

The study area was represented by pedestrian streets surrounding the most prominent holy places that characterize the city of Karbala, which gave it its historical, touristic, and religious importance and which can be developed to occupy a distinguished tourist attraction in the governorate in particular and the country in general [45]. Figures 11 and 12 show the streets and pedestrian movement in the study area.



(a)

(b)

(c)

Figure 12. Pedestrian movement in the streets of the ancient city of Karbala, 2023

11.2 Methods of energy generation at pedestrian footsteps

Table 2 displays how long the bulb illuminates for each footfall and how much energy the gadget stores in response to a person stepping on it.

Table 2. Criteria for footsteps-based energy storage

No of Footsteps	Lighting a 100-Watt, 230-Volt Light for the Duration of (s)	Total Energy (J)
250	6	600
500	12	1200
750	18	1800
1000	25	2500

11.3 Data analysis to measure the energy generated from the streets surrounding holy places

The dimensions of the streets are measured to assess the optimal potential for pedestrian steps. Table 3 and Figure 13 shows that Street D, which branches off from Holy Place 1, has the longest pedestrian street, with a length of about 1,945.31 feet. Meanwhile, the shortest length (Street G) measures 686.63 feet, as shown in Figure 13 and Table 3.

Table 3. Dimensions of pedestrian walkways and number of visitors, 2023

Zone	Length (ft)	Total Number of Pedestrians 2023
A	807.43	4,914,418
B	854.9	2,411,556
C	833.19	2,364,685
D	1,945.31	3,818,262
E	1,212.47	2,941,899
F	1,026.83	2,511,557
G	686.63	863,324
H	1,020.62	2,193,445
sum	8387.38	22,019,146

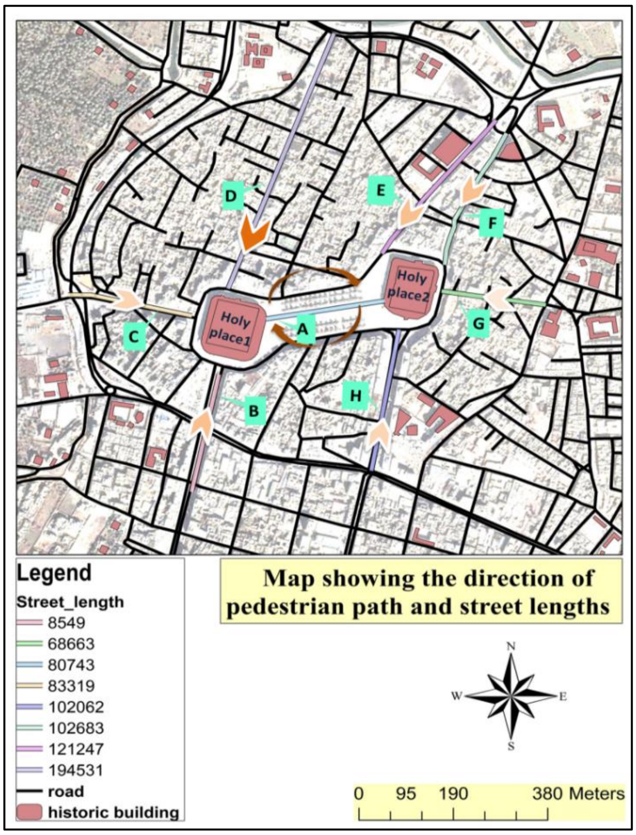


Figure 13. Pedestrian path direction with street lengths 2023

According to the statistics for the year 2023, Figure 14 indicates that the number of pedestrians is high in Zone A by 4,126,254, followed by 3,205.89 in Zone D, while the number decreases in Zone G by 724,866.

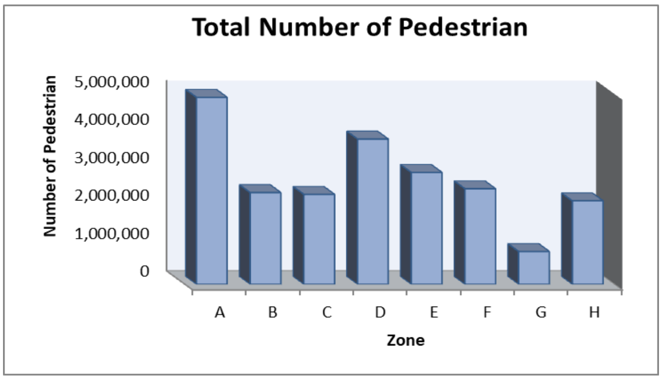


Figure 14. Total number of pedestrians 2023

Where the energy storage device stores the electricity produced by the pedestrian generator. The amount of steps will determine when the lights come on. It looks like this:

(250.00) steps = (6.00) second (s) of duration to lighting a 100.00-watt bulb (1)

Therefore, the number of footsteps needed for every second is:

(250 steps) / (6seconds) x 1 seconds = 41.66 steps = 42.00 steps (2)

Thus, 42 steps are needed every 1 second. Based on the number of pedestrians in Zones (A, B, C, D, E, F, G, and H), it is possible to determine the minimum lighting duration for each zone using the formula 1 second = 42 steps 3.

So assuming:

[Every (2 feet) of interlocking block sidewalk = 1 step] (3)

Table 4. Number of footsteps 2023

Zone	Pedestrian Count	Length – Sidewalk (ft)	Total Amount of Steps
A	4,914,418	807.43	1,984,024,239
B	2,411,556	854.9	1,030,819,737
C	2,364,685	833.19	985,116,033
D	3,818,262	1,945.31	3,713,851,363
E	2,941,899	1,212.47	1,783,481,802
F	2,511,557	1,026.83	1,289,471,155
G	863,324	686.63	296,392,110
H	2,193,445	1,020.62	1,119,336,957
sum	22,019,146	8387.38	12,202,493,396

We note from Table 4 and Figure 15 that the number of visitors' steps heading towards the holy places (1 and 2), especially on days of religious occasions, is high in Zone D, followed by Zone A, which is considered a gathering area and a place for relaxation. In contrast, this corresponds to a noticeable decrease in the number of steps in Zone G.

Based on the data in Table 4 that was entered into the GIS program, we have extracted the following map (Figure 16).

Figure 13 indicates that the central area between Streets E and F, located on the map, has a high amount of footfall. The reason for this is that it is an area where shops and restaurants are gathered.

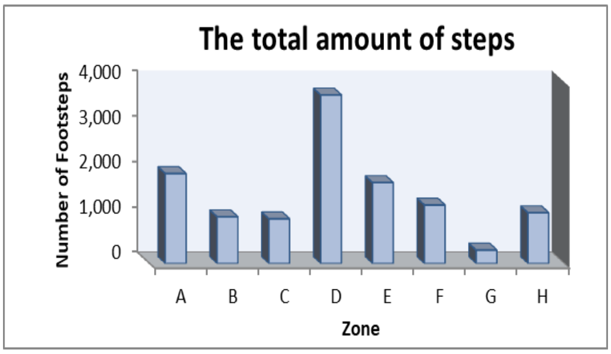


Figure 15. Number of visitors' footsteps in 2023

Therefore, we relied on the data in Table 4 and Eq. (3) to conclude Table 5.

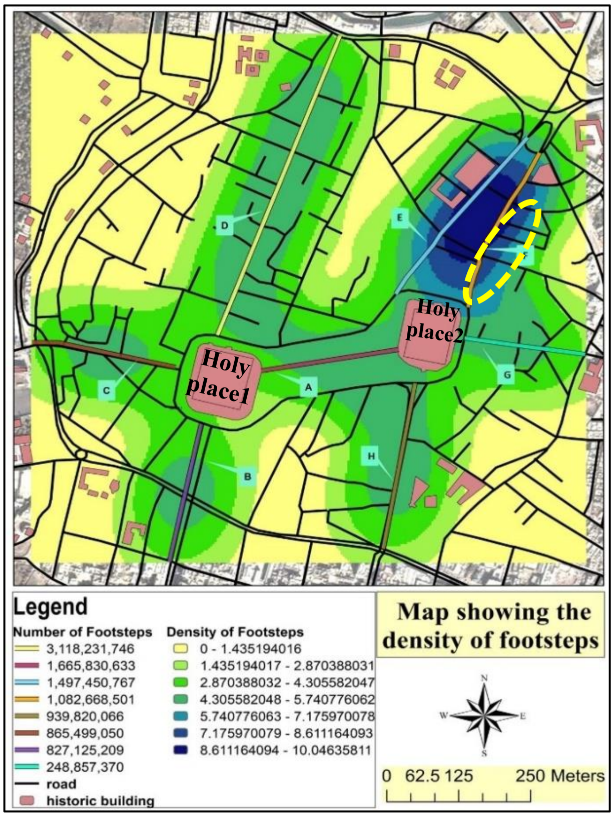


Figure 16. The density of visitors' steps in 2023

Table 5 and Figure 17 show that the amount of energy generated from pedestrian steps passing through the holy places (1 and 2) is significantly high (88,425,032) in Area (D). The reason for the high energy production there is due to the length of the path and the increase in pedestrian steps. Productivity also increases in the central assembly area surrounded by streets (E and F), with a total of (73,165,546) sufficient to light street lamps, illuminate buildings, and operate escalators. This is due to the presence of hotels, shops, and markets. Next comes Area (A), with a productivity of (47,238,672), as this path connects the Holy Place (1 and 2) and is also a seating and relaxation area for crowds, and this is also due to its width. In contrast, the amount of time illuminated by a 100-watt lamp is less in area (C) with a value of (23,455,144), followed by (G) with (7,056,955) seconds. The decrease in energy production is due to the shortness of the path and also the lack of events and activities in it, which leads to fewer pedestrian steps, as shown in Figure 16.

Table 5. Lighting a 100-watt bulb based on footsteps 2023

Zone	Number of Steps	Lighting a 100.00-Watt Bulb for the Duration of (Seconds)
A	1,984,024,239	47,238,672
B	1,030,819,737	24,543,327
C	985,116,033	23,455,144
D	3,713,851,363	88,425,032
E	1,783,481,802	42,463,852
F	1,289,471,155	30,701,694
G	296,392,110	7,056,955
H	1,119,336,957	26,650,880
sum	12,202,493,396	290,535,556

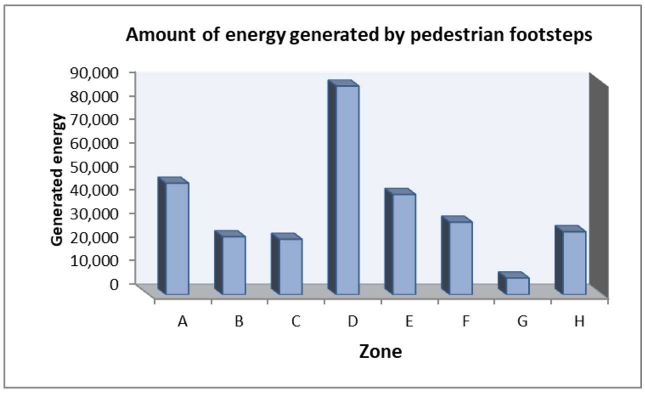


Figure 17. Amount of energy produced by footsteps 2023

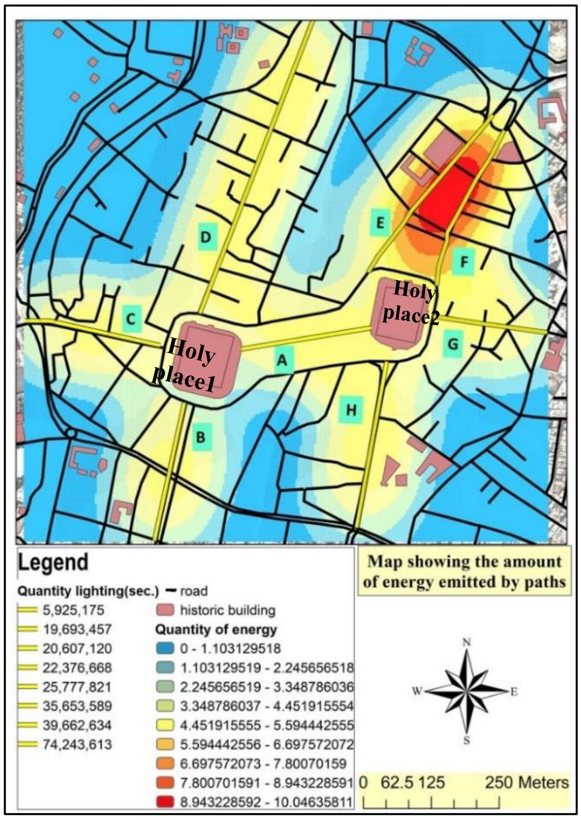


Figure 18. The amount of energy generated in 2023

We conclude from this that based on the number of steps of people taking a street, the illumination time of a 100-watt lamp may change, which affects the duration of energy emission based on the total frequency of pedestrians and the length of the path, as shown in Figure 18. Streets with longer lengths and higher pedestrian frequencies will result in a greater number of steps per street, as shown in Figure 19, and thus, a

100-watt bulb can be lit. Figure 20 shows this. In order to determine whether a light bulb will glow, at least 250 steps must be taken in order to measure how long it will take a 100-watt bulb to ignite in 6 seconds.

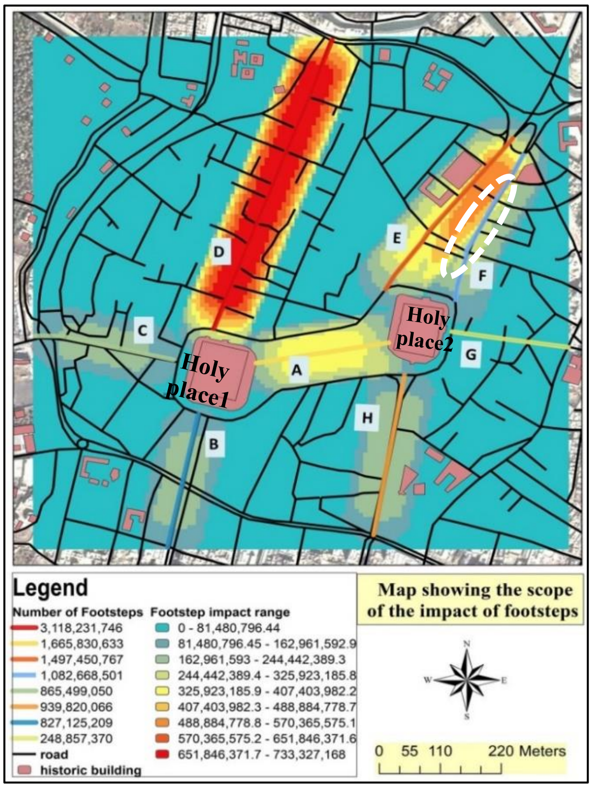


Figure 19. The scope of the steps' impact on the path of 2023

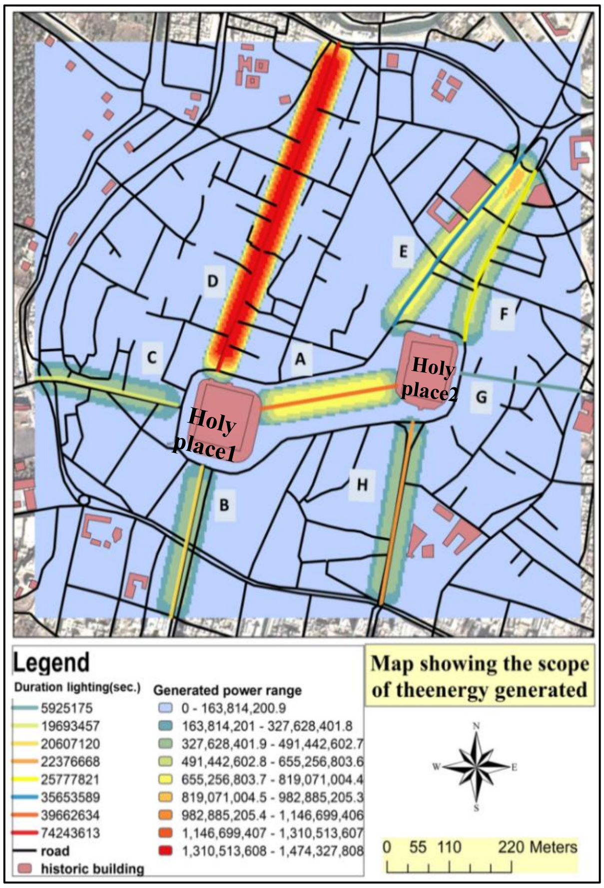


Figure 20. The scope of energy impact on street lighting 2023

Therefore, extracting energy from steps provides many benefits to be achieved, including when converting steps into electricity, we reduce dependence on traditional energy sources and contribute to sustainability. Energy harvesting systems can also be cost-effective and scalable. They use existing infrastructure (such as sidewalks or pavers) without requiring major modifications. Energy harvesting tiles embedded in sidewalks or public spaces turn on LED lights, making walkways safer at night. Also, when we generate electricity through steps, we reduce the environmental impact associated with traditional power generation methods.

However, we do not ignore the consequences and challenges that we may face when applying this technology, including the relatively low energy produced by piezoelectric materials from footsteps. This means that a large number of steps and significant foot traffic are needed to generate a large amount of energy. Implementing energy harvesting technology in public spaces can be expensive. In addition, the materials and devices used must be durable enough to withstand constant use and outdoor conditions, so they require constant maintenance to make this technology more viable.

12. COMPARISON OF ENERGY HARVEST FOR 2022 & 2023

Energy harvesting through the results of 2023 and referring to the results of 2022 as in Table 6 and Figure 21, we note that there is a relative increase in all compared areas. However, we note that the expansion that occurred in sites (1, 2) and the increase in the number of places and approved paths to reach the destination (1, 2) encouraged an increase in the number of steps, as in Table 7 and Figure 22, which was met with an increase in energy harvesting, as in Table 8 and Figure 23. This was clearly evident by comparing the two sites for two consecutive years (2022 and 2023) by increasing the number of areas (E, F, G, H). Thus, we arrive at the concept of spatial suitability that achieves urban sustainability as a result of the increase in the number of paths. Thus, this is accompanied by a relative increase in the number of pedestrians and energy and reaching the main goal, which is (the safe path), which now covers a larger area in 2023. It is expected through our current and previous studies in the field of energy harvesting that the increase will also occur in 2024. Thus, sites (1, 2) become sustainable sites based on the use of clean energy and encourage the achievement of safe and green paths for all religious sites and others.

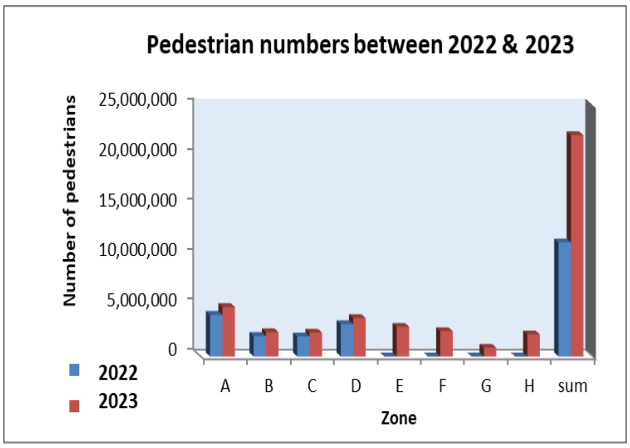


Figure 21. Pedestrian numbers between 2022 & 2023

Table 6. Comparison of pedestrian numbers between 2022 & 2023

Zone	2022	2023
A	4,126,254	4,914,418
B	2,024,796	2,411,556
C	1,985,442	2,364,685
D	3,205,897	3,818,262
E	-	2,941,899
F	-	2,511,557
G	-	863,324
H	-	2,193,445
sum	11,342,389	22,019,146

Table 7. Comparing the number of pedestrian steps between 2022 & 2023

Zone	2022	2023
A	1,665,830,633	1,984,024,239
B	865,499,050	1,030,819,737
C	827,125,209	985,116,033
D	3,118,231,746	3,713,851,363
E	-	1,783,481,802
F	-	1,289,471,155
G	-	296,392,110
H	-	1,119,336,957
sum	6,476,686,638	12,202,493,396

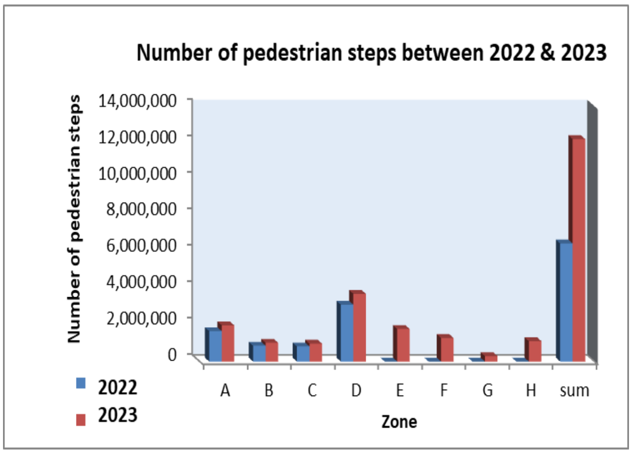


Figure 22. Number of pedestrian steps between 2022 & 2023

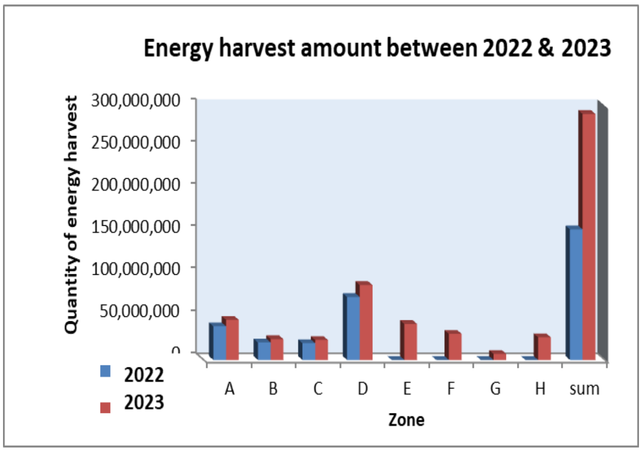


Figure 23. Quantity of energy harvest between 2022 and 2023

Table 8. Comparison of the amount of energy harvested between 2022 & 2023

Zone	2022	2023
A	39,662,634	47,238,672
B	20,607,120	24,543,327
C	19,693,457	23,455,144
D	74,243,613	88,425,032
E	-	42,463,852
F	-	30,701,694
G	-	7,056,955
H	-	26,650,880
sum	154,206,824	290,535,556

13. CONCLUSIONS

1. Implementing this technology could help develop environmentally friendly corridors that not only provide a safe path but also contribute to energy generation and urban sustainability.
2. It is a renewable and sustainable source of energy, as it relies on human movement, which is naturally occurring and abundant in places like sidewalks, malls, and airports.
3. This method supports the decentralization of power generation, allowing energy to be produced at the point of consumption, potentially reducing transmission losses and reliance on centralized power grids.
4. The amount of energy generated is relatively small, with each step producing between 2 to 4 joules of energy, enough to power an LED bulb for about 30 seconds.
5. The cost-effectiveness and practicality of implementing such systems on a large scale are still under consideration. The technology involves an initial investment for the installation of specialized flooring materials equipped with energy-harvesting technology.
6. By providing an alternative to traditional energy sources, this technology can contribute to reducing the carbon footprint and mitigating the effects of climate change.
7. Such initiatives can increase public awareness about renewable energy and encourage community involvement in sustainable practices.
8. Based on the increasing numbers of visitors during religious occasions and their movement in the streets surrounding Holy Places 1 and 2, it can be concluded that paths (D, E, F, and A) are the most used by crowds compared to other areas and paths.
9. The study area plan is flexible, which allows crowds to be managed during different seasons.
10. Through our current and previous studies in the field of energy harvesting, the increase will also occur in 2024. Thus, sites (1 and 2) will become sustainable sites based on the use of clean energy and encourage the achievement of safe and green paths for all religious sites and others.

14. RECOMMENDATIONS

1. Similar to piezoelectric tiles, kinetic pavements are designed to generate more energy and can be integrated into walkways.
2. Stairs can also be equipped with energy-harvesting technology to capture the energy from people stepping on them.

3. The materials used should be highly durable and easily integrated into existing infrastructure.
4. The harvested energy is typically stored in batteries that can power lights or other devices. Each step can produce enough energy to operate an LED bulb for 30 seconds.
5. Selecting locations with high pedestrian traffic will maximize energy production.
6. Combining pedestrian-friendly walkways with hybrid renewable energy technologies can develop green concepts for pedestrian paths in cities.
7. The findings indicate that there is a great deal of potential for energy harvesting from footfall; however, sidewalks need to be made better beforehand.
8. Conduct periodic detailed urban and planning studies for all visitation sites, taking into account crowd movement and their diverse activities.
9. Continue harvesting energy for five consecutive years for the purpose of launching forecasts for the coming years and medium and long-term plans to achieve the goal of sustainable development in renewable energy.

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