Spatial Suitability of Electric Mobility Paths for Crowds in the Holy City of Karbala (Paths Leading to the Holy Shrines of Imam Hussain and Abbas)

Baydaa Abdul Hussein Bedewy
University of Kufa
baidaaa.bedewy@uokufa.edu.iq

Dhuha Algburi
University of Kufa
dhuhaw.algburi@uokufa.edu.iq

Marwan H. Abdulameer
College of Environmental Science, Al-Qasim Green University
marwan.hussein@wrec.uoqasim.edu.iq

Abdul Sahib Naji Al-Baghdadi
University of Kufa
abdulsahib.albaghdadi@uokufa.edu.iq

Abstract

The spatial alignment of kinetic energies falls within the realm of green smart city technologies, such as smart streetlights and traffic signals. These advancements are among the latest examples of innovative infrastructure that aim to establish the region as a leading city in smart technology within the country.

Despite pedestrians having individual preferences, goals, and destinations, the dynamics of pedestrian crowds of visitors can surprisingly be predicted. Pedestrians can move freely in sparsely populated areas, but during peak times of million visit and increased crowds, they require self-organization and movement along guided smart pathways that generate green energy. In such cases, pedestrian pathway systems will evolve, and computer simulations will be valuable tools in developing distinctive pedestrian facilities and road track systems.

This research aims to investigate the management of human crowds of visitors during the annual million-visitor seasons in Iraq, specifically focusing on their organizational role and protection from the risks of congestion and overcrowding while performing sacred rituals in the holy cities of Karbala surrounding the holy shrines of Imam Hussein and Abbas.

The study found that human activities can contribute to generating electricity through energy-harvesting activities such as walking. When a person walks, energy is dissipated on the surface through impact and vibration, which can be harnessed and converted into electrical energy. Therefore, the study area, represented by the city of Karbala, stands out as a place where crowds gather, with millions of people from various nationalities congregating inside and around its squares and passages during the fortieth-day of Imam Hussein,(peace be upon him) pilgrimage and other religious visits. This necessitates providing large quantities of energy consumed in lighting, escalators, air conditioning, and other operational needs.

The research revealed an untapped and essential element for clean energy generation, which is the kinetic energy resulting from the movement of the visitors. This study aims to propose a system for crowds of Ziyarte Al-Arba'een management by accurately understanding pedestrian density through smart applications for the piezoelectric tile system. The research methodology involved using geographic information systems to identify the routes where the system is applied to achieve the highest energy harvesting ratio for optimal utilization.

Keywords: Ziyarte Al-Arba'een , Sustainability, Pedestrian Pathways, Sustainable Energy, Crowds, Smart Pathway.

1. Introduction

Affordable and sustainable energy is the key to sustainable development. Energy remains essential for social and economic well-being, poverty eradication, ensuring a healthy life, and improving living standards. Achieving a future energy system requires sustainable management of natural resources, ensuring innovative production and consumption, and promoting sustainable manufacturing that enhances the development of flexible energy infrastructure. Proper and coordinated planning for system development is also crucial. The year 2015 was significant in framing future international energy and climate goals. The 2030 Agenda provides a framework, and the Sustainable Development Goals (SDGs) were agreed upon. While Goal 7 of the SDGs targets "affordable and clean energy for all," it is not the only energy-related goal [1].

Pedestrian crowds of visitors have been studied experimentally for over three decades [2]. The main objective of these studies has been to develop the concept of service level, the design elements of pedestrian facilities, and planning guidelines [3].

None of these concepts adequately consider the self-organisation effects in pedestrian crowds. However, such effects can lead to unexpected obstacles [4].

Due to the variation in pedestrian flows, it became more evident, as described by Henderson's approach, who predicted that the behavior of pedestrian crowds is similar to that of gases or liquids [5, 6, 7, and 8].

"However, a realistic gas kinetics theory or fluid dynamics for pedestrians must consider corrections due to their specific interactions (e.g., avoidance, deceleration, and maneuvers) that do not inherently preserve momentum and energy. 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].

In human crowds and many animal communities, local interactions among individuals often lead to self-organization and recurrent local interactions, 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. The self-organized movement pattern enhances traffic flow by reducing frictional effects, local acceleration, energy consumption, and walking delays [14].

In human crowds, functional movement patterns have been identified several times in the past, such as the oscillatory flows at bottlenecks [15], corridor formation [16], or walking and the formation of social categories [17]. The variation in pedestrians' walking speeds is a key variable in the origin of noticeable traffic disruptions. We demonstrate that the collective benefit of the emerging pattern is maximised when all pedestrians walk at the group's average speed in practice. However, local interactions between slow and fast walkers lead to a global breakdown of organization, reducing the collective

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and individual gains provided by traffic separation. This work is a step forward in understanding the self-organization of traffic movement in crowds, which is influenced by complex behavioral mechanisms [18].

The quantitative understanding of road crowd behaviors for bottom-up management design requires compelling strategies to promote effective collective behaviors in crowds. Crisis management is an approach to dealing with emergencies to control their outcomes or minimize their negative effects. Moreover, crowds of visitor's management and organization pose significant challenges for officials during peak million 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 of visitors 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.

The Research Problem:

1. Several million visitors gather simultaneously inside the two shrines and surrounding areas, requiring a significant amount of energy for lighting, escalators, air conditioning, fans, and other operational needs.
2. What are the efforts and pre-planned strategies of the shrines in crisis management, Crowds of visitors control, and organizational work to achieve sustainable energy?

Research Objective: The main objective of the research is to contribute to crisis management and crowd organization by generating green energy based on the movement of visitors, reducing dependence on fossil fuels and their environmentally harmful emissions through smart pedestrian pathways.

Research Hypotheses:

There is a relationship between the efforts and pre-planned strategies of the shrines in crisis management and crowd control.

Developing a crowd management system using smart applications through precise knowledge of pedestrian densities.

2. Research Methodology:

The research adopts a descriptive-analytical approach in managing crowds of visitors and organizing human gatherings during Million visit pilgrimage seasons, especially during the Ashura visit, Tawerij run, The fortieth day of Imam Hussein,(peace be upon him) and other visits.

3. Sustainable Energy:

There are various interpretations of "sustainable energy," and for this research, it is adopted based on its role in economic, social development, and environmental impact. "Sustainable energy" is defined through three pillars, encompassing the key objectives of sustainable development:

(1) Energy security, (2) Energy and quality of life, (3) Energy and the environment (see Figure1).

These relevant objectives of sustainable development are aligned with the three pillars of sustainable energy, considering the interconnectedness of different aspects of sustainable energy and the challenges countries may face while transitioning towards a sustainable energy region.

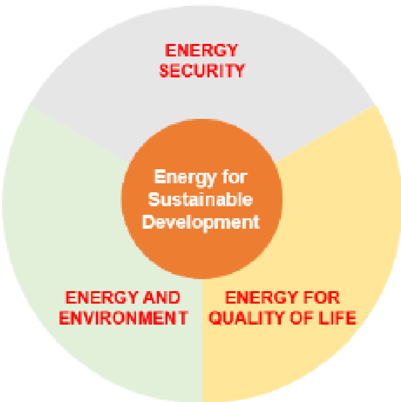

Figure 1: Energy for sustainable development

Energy Security: Securing the energy needed for economic growth. The Energy Security axis deals with the economic aspects of safe energy from a national perspective. It includes access to energy supplies, including import, export and transit.

Energy security ensures that energy contributes optimistically to the country's social, economic and environmental development. It requires countries to adopt more innovation in development policies. To ensure that they are alert to changes, adapt in response, and build resilience to deal with all the variables and emergencies they go through [21].

Energy for Quality of Life: Providing affordable energy at all times.

The pillar of energy for quality of life aims to improve the living conditions of citizens by achieving clean, reliable, and affordable energy for all. This objective encompasses physical access to electricity grids and the quality and ability to bear the costs associated with accessing a broader concept of energy services. These services include electricity, heating, cooling, and transportation, which are crucial for enhancing the overall quality of life.

Energy and Environment: Reducing the impact of energy on the climate system, health and environmental systems.

The third pillar of energy and the environment represents the trade-offs between meeting the growing energy demand, providing a healthy environment with clean air and protecting humanity from climate change. Energy emissions contribute 60% of the total greenhouse gas emissions. Hence, the energy sector must reduce its carbon footprint across the supply chain to support climate and change mitigation efforts. [22, 23].

SDG 9 covers the energy industry, energy-intensive industries, energy innovation, and comprehensive energy infrastructure. Achieving

SDG 9 requires an energy transition geared towards achieving the SDGs as resilient infrastructure, sustainable energy and resource use, and the development, deployment and local adaptation of energy technology.

Goal 11 of the Sustainable Development Goals, with the transition and development of sustainable urban energy capable of resilient infrastructure, sustainable energy supplies for cities and urban and rural communities, transportation sustainability, and the development of sustainable transportation fuels [22].

Within the "Energy for Wellbeing" pillar, the most important energy-related SDGs are Goal 2 on "Zero Hunger", SDG 7 on "Affordable and Clean Energy", SDG 11 on "Sustainable Cities and Communities", and SDG 17 on "Partnerships." SDG 2 is related to the energy sector through the food-energy-water nexus due to competition for resources with the food sector. Agriculture is water and energy, and bioenergy may compete with food production like Maise [21]. Note Figure2.

And this interdependence between the sustainable goals and their interdependence with the organisation of crowds and their management by taking advantage of the kinetic energy to generate electrical energy by organising the paths of the crowds during the visits at the holy thresholds.

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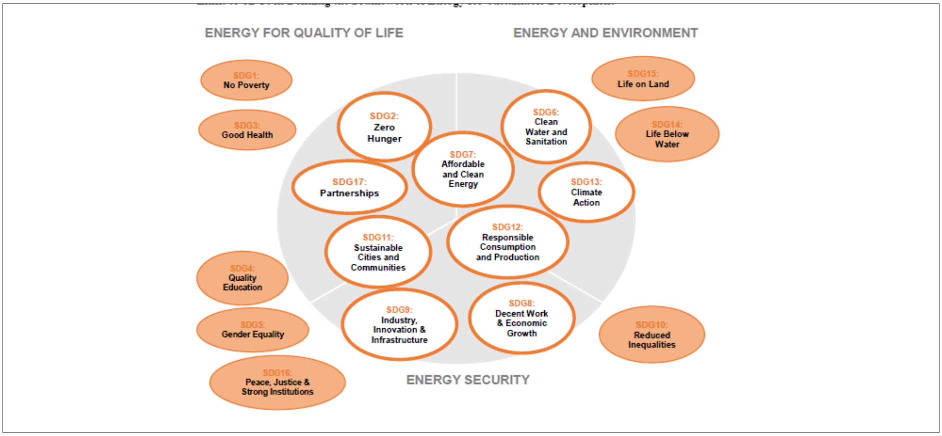

Figure 2: Links to the SDGs in defining the Energy Framework for Sustainable Development

4. Crowd Organization:

The newly emerged science of managing crowds or human gatherings is considered an independent science. It has its concepts, theses and methods. Many countries have paid attention to this science because of the people's need for it. Every country establishes this science from its perspective in dealing with human crowds, whether those crowds come to it through international programs such as holding international exhibitions, or international sporting events that attract millions of people in a specific period and a specific place, and how to deal with those crowds in their housing and transportation Providing them with health services, and how to deal with them in case of riots [24].

4.1. Concept of Crowd Organization:

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

4.2. Crowd Classification:

Crowds can be classified based on several criteria, including:

3. The location and boundaries of the event or occasion where the individuals gather.
4. The time period of the gathering.
5. The purpose of the crowd gathering.
6. The starting time of the gathering.
7. The level of cohesion among the crowd members.
8. The surrounding conditions and atmosphere of the event or occasion.

4.3. Types of Crowds:

1. **Orderly Crowd:** Occurs in well-known events, such as football matches.
2. **Active Crowd:** Characterized by emotional behavior and intensity, seeking to achieve specific demands.
3. **Expressive Crowd:** Individuals gather to perform shared rituals expressed through movements, like a group of worshipers.
4. **Casual Crowd:** Formed spontaneously without prior planning, like a gathering of individuals at a car accident site.

5. Smart Pedestrian Pathway:

The traditional pedestrian pathway is made of marble floors, lacking any shaded areas for pedestrians during sunny conditions.

The sides of the pathway are usually marked by police or barriers, or sometimes both. The idea of a smart pedestrian pathway involves using flooring materials that can generate electricity from the walking movement, converting kinetic energy into electrical energy (electro-pressure tiles).

6. Electro-Pressure Tiles:

This system appeared in 2009 in the United Kingdom and has been applied in more than 100 projects at the level of 30 countries in airports, train stations, public places and commercial places. This system has received more than 20 awards for innovation and creativity in the field of renewable energy. His idea is based on piezoelectric tiles measuring 60 * 45 cm and a thickness of 6.8 cm, as shown in the figure. It converts the pressure of walking into mechanical energy, then it is converted into electrical energy through a dynamo and stored in lithium batteries. [29].Fig 3.

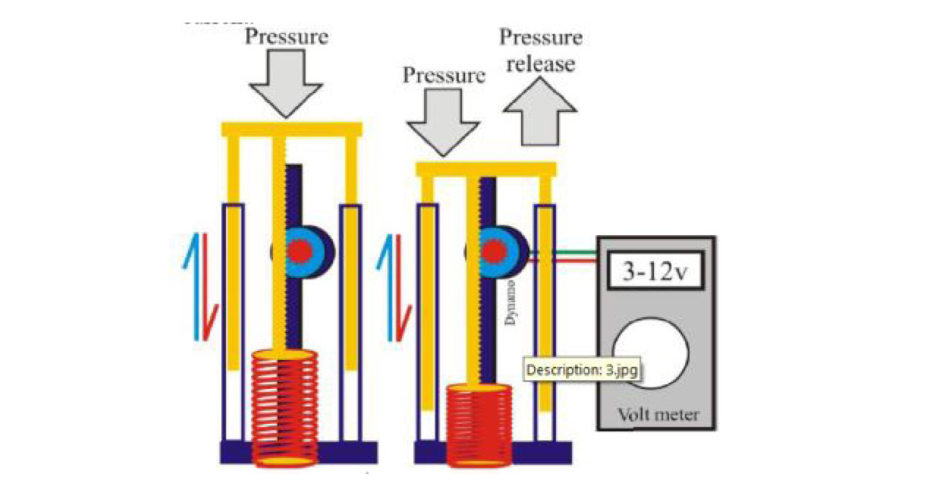

Fig (3) : Shows how to make a pedestrian path slab

7. Sustainable Energy from Walking Steps:

Renewable energy sources like solar, wind and hydropower need high investment costs. Therefore, to overcome these problems, many efforts have been made to make energy sources renewable and environmentally friendly [30]. Walking is the most popular activity that is done every day and can produce energy. Every time someone steps on a tile, the kinetic energy from their footsteps is converted into renewable electricity. This electricity can be used to power lighting, advertising screens, or communications networks or stored in a battery for later use.

The majority of university students prefer to use walking for them to go to the site. Through this method, sustainable energy footsteps can be implemented. By using weight energy, it can gain electrical energy. It's a simple concept. A person only needs to walk on the ground at a normal speed and can see how much energy one person produces. Using this concept, the energy produced is environmentally friendly. They can also be effective ways to save money because you don't need any fuel or energy sources by walking. It's just a simple way to follow [31].

8. Benefits of Walking

Walking is an activity that all humans do. This method can provide a variety of positive effects on the body and reduce the negative impact on the environment. For example, it can reduce air pollution and it can also produce sustainable energy from steps. The university is one of the locations where most of the population uses walking as a position to perform any activity. Therefore, the university can be used as a benchmark for the effectiveness of conducting a study in the footsteps of a feasibility study based on the energy harvesting potential of Light Walkers[32].

9. Ways to Generate Electricity from Pedestrian Footsteps:

Daily activities such as walking by humans can produce a lot of energy. On average, humans walked about 3,000 - 5,000 daily newspapers. According to [33], the process of obtaining the energy surrounding the system and converting it into usable electrical energy is called energy harvesting. It is also possible to convert kinetic energy into electrical energy using footwork.

There are two power generation methods: step-by-step electrical transformer devices and electricity generation steps using Pavegen. The first method when placed in the sidewalk area, has the ability to convert kinetic energy into electrical form. The downward movement of the plate causes the shaft of the electric generator installed in the device to rotate, producing electrical energy. The electricity generated by these devices can be used for street lighting. But the efficiency of the device to function properly is limited. Table 1 shows the duration of the illumination, the lamp for the number of footsteps and the corresponding energy stored by the device that was triggered by a person walking on it.

There are two ways to generate electricity using piezoelectric devices on walkways. The first method involves placing the devices on pedestrian pavements to convert kinetic energy into electrical energy. When the plate undergoes a downward motion due to a footstep, it rotates the dynamo, generating electrical power. This electricity can be used to illuminate street lights. However, the efficiency of the device is limited.

10. Potential Locations for Electricity Generation from Pedestrian Pathways:

Different piezoelectric generators cannot be implemented in different places as long as there is repeated application of pressure. For example, a location that has a high frequency of vehicular traffic

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takes place and places where a large group of people hang out. Roads, shopping malls, footpaths, railroad tracks, and highways are the most common locations for these conditions. The site broadly includes streets, highways and railway tracks. Traffic conditions on streets and highways vary throughout the day with traffic being heavier in the morning than at night and sometimes 24 hours a day. A railway track is one example of huge power generation because the trains exert enormous pressure on the railway tracks. Piezoelectric material pads are placed at the junction where the wheel makes contact with the tracks and receives maximum pressure such as is used on airport runways, and the pads are arranged so that a greater force is to be tolerated and a greater amount of charge is stored [34].

11. The Sidewalk:

In the context of traffic, the meaning of sidewalk is very broad. It is closely related and has a line meeting between the environment and human activities and movements. Therefore, pavement can be defined as the road/space/pedestrian walkway/special paved walkway designed/made for pedestrian use. Sidewalks are one of the sustainable transportation systems. Through walking, it can be a viable option that can also produce healthy physical activity [35].

Walking energy can be harvested and converted into electrical energy using piezoelectric materials. The result of observations and surveys in the case study shows that 46,000 pedestrians walk along the walkway with an average weight of 66.40 kg per day. Assuming the length of the trail, that number of steps and amount of weight would theoretically be enough to generate 6,130 watts of electrical energy per day. Therefore, the use of piezoelectricity in the case study floor is a promising way to generate electricity for the corridor lighting system based on renewable energy. This study contributes to preserving fossil fuel energy and using renewable energies as a clean and sustainable source. Since the model used is based on walking mechanisms and human behaviors, it is recommended to check other theoretical models, in order to accurately obtain the acting force and consider other effective factors such as pedestrian speed and stride length as well.Table1.

Table (1): Effective factors that must be taken into account to generate energy from pedestrian footsteps

Available service	technology	Context	Energy type
power consumption of the device	Efficiency of piezoelectric materials	Walkway length	number of steps
number of devices		number of pedestrians	foot pressure Pedestrian stride length walking speed

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12. The practical side

12.1. Study area

The study area is represented in the city of Karbala, in the area surrounding the two Imams, which is represented by the Husseini and Abbasid shrines, and other shrines within the area of the visitation.

12.2. Methods of Energy Generation at Pedestrian Footsteps:

Table 2 shows the duration of lamp illumination for the number of footsteps and the corresponding energy stored by the device triggered by a person walking on it.Table 2.

Table 2. Energy Storage by Foot Steps

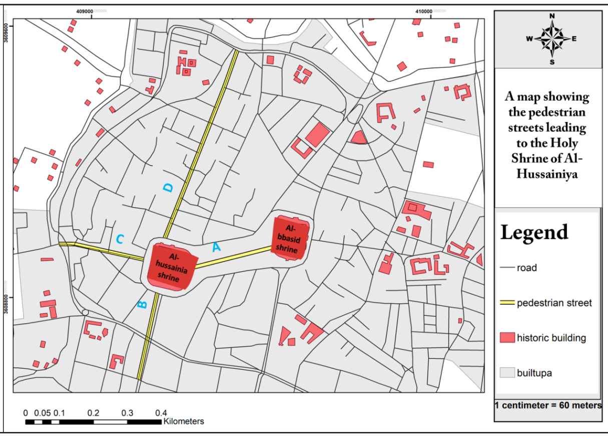
No of Foot Steps	Duration of Lighting a100 watt 230volt bulb (s)	Total energy (J)
250	6	600
500	12	1200
750	18	1800
1000	25	2500

12.3. Data analysis to measure the energy generated from the site:

1. **Al-Hussainiya threshold:** the dimensions of the streets are measured to assess the optimal potential for pedestrian steps. Table 2 shows that Street D, which passes through the Holy Shrine of Al-Hussainiya, has the longest pedestrian street, which is about 1,945.31 feet. Meanwhile, the shortest length of Street A is 807.43 feet. As shown in map (1) and table (3).

Table (3) Dimensions of pedestrian walkways and number of visitors

Zone	Length(feet,ft)	Total Number of Pedestrian
A	807.43	4,126,254
B	854.9	2,024,796
C	833.19	1,985,442
D	1,945.31	3,205,897



Map (1) places the pedestrian streets associated with the Holy Shrine of Al-Hussainiya

Where the power can be generated by the pedestrian generator, which is stored in the energy storage device. The number of steps will affect the time the lights turn on. It is as follows:

250 steps = 6 second (s) of duration to lighting a 100-watt bulb

Hence, for every 1 second, the numbers of footsteps required are:

(250 steps)/ (6 seconds) x 1seconds = 41.66 steps = 42 steps.

Therefore, every 1 second, 42 steps are required. According to the frequency of pedestrian in Zone A, B, C & D, the minimum duration of lighting for each zone can be evaluated based on 1 second = 42 steps.

However, by assuming:

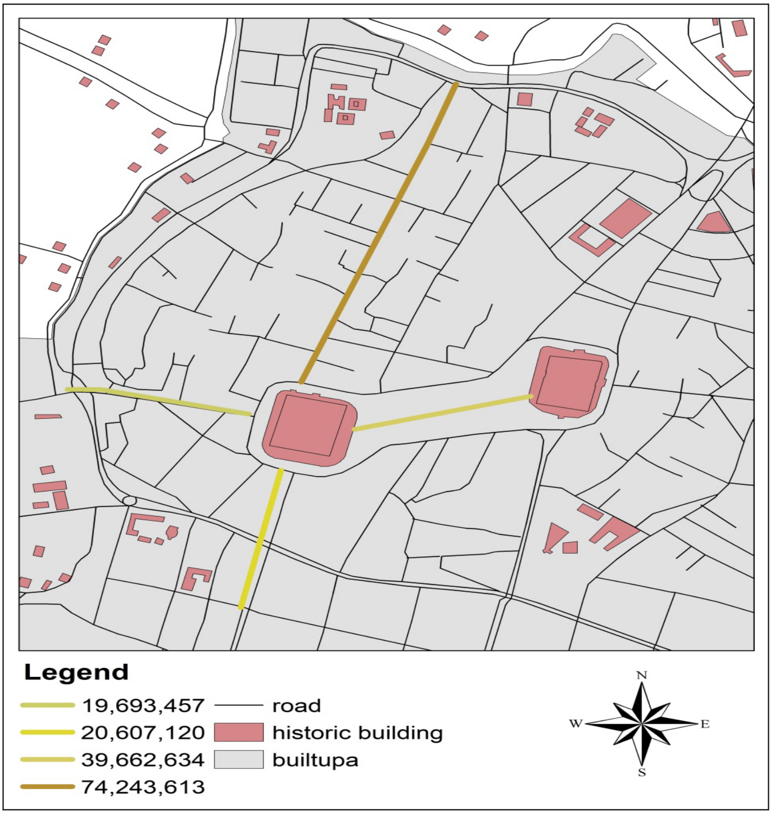
Every 2 feet of interlocking block sidewalk = 1 steps

Table 4. Number of Footsteps

Zone	Total Number of Pedestrian	Length of Sidewalk (feet,ft)	Total Number of Footsteps (Steps)
A	4,126,254	807.43	1,665,830,633
B	2,024,796	854.9	865,499,050
C	1,985,442	833.19	827,125,209
D	3,205,897	1,945.31	3,118,231,746

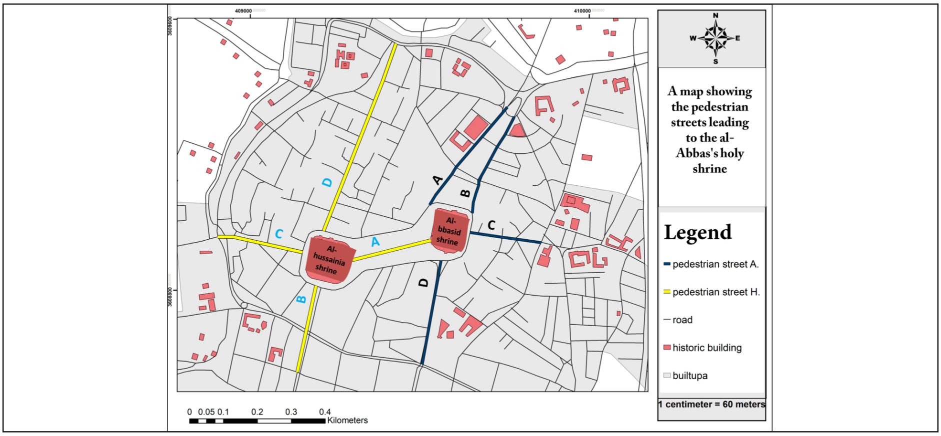
Table 5. Duration of Lighting a 100-Watt Bulb Based on Number of Footsteps

Zone	Number of Steps (steps)	Duration of Lightinga100-watt Bulb (second,s)
A	1,665,830,633	39,662,634
B	865,499,050	20,607,120
C	827,125,209	19,693,457
D	3,118,231,746	74,243,613



Map (2) The potential for power generation is placed depending on the visitors' footsteps

2. The Abbasid threshold: Table 5 shows that Street A, which is linked to the al-Abbas's (p) holy shrine, has the longest pedestrian street, which is about 1,212.47 feet. Whereas, the shortest length of Street C is 686.63 feet. As shown in map (3) and table (6).



Map (3) places the pedestrian streets associated with the al-Abbas's (p) holy shrine

Table (6) dimensions of pedestrian walkways and number of visitors

Zone	Length(feet,ft)	Total Number of Pedestrian
A	1,212.47	2,470,083
B	1,026.83	2,108,759
C	686.63	724,866
D	1,020.62	1,841,665

Based on the previous steps, we have Tables (7) and (8):

Table (7) Number of Footsteps Calculated

Zone	Total Number of Pedestrian	Length of Sidewalk (feet,ft)	Total Number of Footsteps (Steps)
A	2,470,083	1,212.47	1,497,450,767
B	2,108,759	1,026.83	1,082,668,501
C	724,866	686.63	248,857,370
D	1,841,665	1,020.62	939,820,066

Table (8) Duration of Lighting a 100-Watt Bulb Based on Number of Footsteps

Zone	Number of Steps (steps)	Duration of Lightinga100-watt Bulb (second,s)
A	1,497,450,767	35,653,589
B	1,082,668,501	25,777,821
C	248,857,370	5,925,175
D	939,820,066	22,376,668

Map (4) The potential for power generation is placed depending on the visitors' footsteps

Table 4 illustrates that the amount of energy emission for the paths passing through the Holy Hussein threshold is significantly high (74,243,613) in region D, while it becomes lower in region C with a value of 19,693,457. On the other hand, the duration of a 100-watt bulb's illumination in the streets associated with the Holy Abbas threshold is higher in region A compared to regions B, C, and D, with a total of 35,653,589 readings per second. Additionally, energy generation is low in region C, amounting to 5,925,175 seconds, as indicated in Table 7.

The duration of the 100-watt bulb's illumination may vary depending on the number of footsteps, which affects the emission duration of energy based on the total pedestrian frequency and sidewalk length. Streets with higher pedestrian frequencies and longer sidewalks will result in a larger number of footsteps per street, which, accordingly, can illuminate a 100-watt bulb. To verify whether the bulb will light up, a minimum of 250 footsteps is required to assess the time it takes for the 100-watt bulb to illuminate within 6 seconds.

13. Conclusions:

1. The implementation of the pedestrian energy-harvesting pathway project transforms the areas surrounding the holy shrines into sustainable green zones, providing a place for visits, scientific exploration, and creativity.
2. Based on the increasing number of visitors during the fortieth-day of Imam Hussein, (peace be upon him) visitation period and their movement in the streets around the holy shrines, it can be inferred that paths D and A are the most used by the crowds compared to other regions and paths.
3. The shrines have pre-planned crisis management and Crowds of visitors control strategies, regularly updating and developing them.
4. The shrines collaborate and coordinate in implementing their plans with all relevant authorities involved in crowd and crisis management to ensure the success of their crowd of Million visit management plans.
5. The shrine's plans are distinguished by their ease of implementation

and flexibility, enabling effective Crowds of visitors management during various visitation seasons.

14. Recommendations:

1. Based on the results, there is significant potential for harvesting energy from footsteps, but the quality of sidewalks should be improved in advance.
2. It is also recommended to expand the use of energy harvesting in multiple locations, such as shopping centers, airports, hospitals, and other places.
3. Develop a crowd management system using accurate data on pedestrian densities through smart applications and piezoelectric tile systems, which will assist in managing crowd movement during the forty-day and Sha'ban visitations.
4. It is essential to have alternative plans in case of any disruptions to the primary set plans, which positively impacts crowd management.
5. Strengthen coordination with relevant authorities in implementing the shrines' crowds of visitors and crisis management plans.
6. Focus on technological advancements and updates in devices and technologies that aid in crowd management during the visitation season.
7. Give importance to urban design and planning to control crowd movement and enable them to engage in various activities at event and gathering sites.
8. Conduct periodic detailed urban and planning studies for all visitation sites, taking into account crowd movement and their diverse activities.

9. Embrace sustainable energy with its three pillars in all service sectors, especially in religious areas and holy sites.
10. Invest in crowd movement and organization to generate and achieve sustainable energy in larger pathways, resulting in a higher percentage of sustainable energy production.

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