"PowerWalk"- Sustainable Energy Tiles harnessing Footstep Energy

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Abstract -

The increasing demand for sustainable energy solutions and the growing challenges of urbanization have compelled innovators to explore new avenues for harnessing clean energy. Sustainable energy sources harness naturally replenishing sources of energy to generate power without depleting finite reserves or emitting greenhouse gases. These sources offer a clean and enduring solution to the world's energy demands reducing dependence on non-renewable fossil fuels. The "PowerWalk" project presents an innovative sustainable energy tile that capitalizes on the kinetic energy produced by human footsteps in high footfall urban areas. Through the utilization of piezoelectric sensors the prototype efficiently converts footstep-generated mechanical stress into electrical energy. This paper delves into the design and construction of the "PowerWalk" tiles, its optimization for energy-harvesting. The study also highlights the materials' selection, mechanical strength, and the impact of PowerWalk in reducing carbon emissions by providing renewable energy sources in urban environments. The future scope of the project explores diverse implementation areas, and the environmental implications of large-scale adoption. The "PowerWalk" prototype showcases a promising and practical solution for promoting sustainable energy initiatives and creating cleaner and greener urban landscapes.

Key Words: Sustainable Energy, Footfall, Mechanical Energy, Piezoelectric Sensors,

1.INTRODUCTION

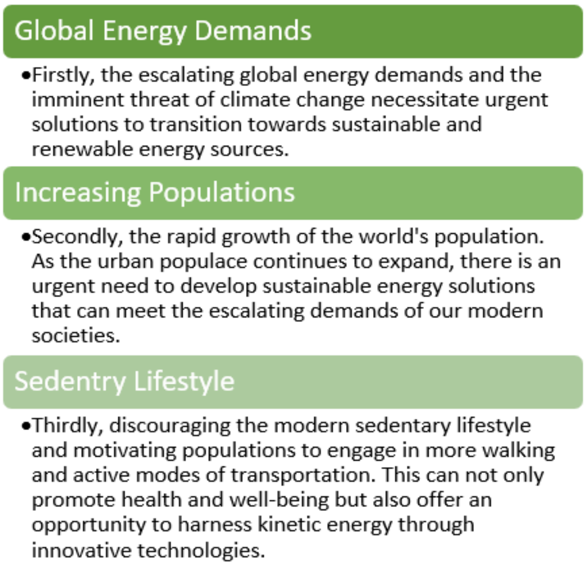
Conventional energy generation methods, predominantly reliant on fossil fuels, have proven detrimental to the planet's delicate ecological balance. The energy sector is responsible for approximately [1] 73% of global greenhouse gas emissions (IEA, Global Energy & CO2 Status Report 2020), underscoring the urgent need to transition to sustainable and low-carbon energy sources. M

Harvesting energy is one of the most effective ways in which we can combat this issue. In this light, with the number of people residing in cities steadily rising there is a dynamic realm of bustling activity, particularly in high footfall areas. According to the United Nations' projections, [2] approximately 68% of the world's population is expected to live in urban areas by 2050, making sustainable energy solutions in cities crucial for global emissions reduction. Pavements can serve more than a space for walking. The sheer magnitude of pedestrian traffic in these urban centers presents an untapped reservoir of kinetic energy. High footfall areas have an [3] average of 70 to 100 steps per minute during peak hours (Journal of Physical Activity and Health, 2011). By converting the kinetic energy produced by human footsteps into usable electricity, a unique opportunity is presented to capture renewable energy from an inexhaustible source - pedestrian movement.

The seamless integration of these tiles into public spaces and high-footfall areas offers a dual benefit: supplementing the local power grid with clean energy and encouraging public engagement with sustainable practices. The conversion of these everyday movements into electrical power offers a compelling opportunity to harness clean energy with seamless integration into public spaces without disrupting urban environments or requiring additional resources.

1.1 Problems Addressed

This research project focuses on addressing several critical problems including sustainable energy, the increasing population, and promoting physical activity through walking.



Global Energy Demands

- Firstly, the escalating global energy demands and the imminent threat of climate change necessitate urgent solutions to transition towards sustainable and renewable energy sources.

Increasing Populations

- Secondly, the rapid growth of the world's population. As the urban populace continues to expand, there is an urgent need to develop sustainable energy solutions that can meet the escalating demands of our modern societies.

Sedentry Lifestyle

- Thirdly, discouraging the modern sedentary lifestyle and motivating populations to engage in more walking and active modes of transportation. This can not only promote health and well-being but also offer an opportunity to harness kinetic energy through innovative technologies.

Fig -1: Final PowerWalk Model

Addressing these interconnected problems requires innovative approaches and sustainable energy solutions that promote environmental consciousness and the adoption of healthier lifestyles.

2. PROPOSED SOLUTION

Fig -2: Final PowerWalk Model

The proposed prototype, "PowerWalk," is an innovative sustainable energy tile concept specifically tailored for seamless integration within bustling urban pavements, where high footfall areas pave the way for a rich source of kinetic energy waiting to be harnessed. Each PowerWalk tile contains an arrangement for piezoelectric sensors, foam, and springs sandwiched between triangular plywood sheets. With six piezoelectric sensors and six springs in each tile, the pressure on the sensors is optimized to convert mechanical stress into electrical current. Beyond its energy-harvesting capabilities, PowerWalk also exemplifies user-friendliness. Adorned with LED lights on each tile, this device communicates to passersby, instilling an environmental consciousness and fostering a sense of appreciation for sustainable innovations. By connecting each tile in series, the voltage generated during use is increased. This energy is then directed to a lithium battery to ensure efficient and practical utilization of the harnessed energy, making PowerWalk a dependable and self-sustaining source of renewable electricity.

2.1 Scope

This project's focused scope revolves around testing and optimizing various models and mechanisms for these Sustainable Energy Tiles. Through rigorously evaluating piezoelectric sensors and materials, the aim is to identify the most efficient energy conversion mechanism from footstep-generated mechanical stress. The ultimate goal is to create a functional prototype of six tiles that can effectively harness kinetic energy from high-footfall areas. Comprehensive performance evaluations will guide design refinements and economic feasibility considerations, contributing to a sustainable future.

2.2 Importance of Kinetic Energy harvesting

The human body possesses abundant kinetic energy due to its dynamic movements, sudden accelerations, and substantial displacements. This inherent energy potential can be harnessed as a viable power source, offering an intriguing supply option for low-power electronic devices with power density levels of $1mW/cm^3$ or 1mW/g. Utilizing piezoelectric transduction during activities like walking, with a frequency of approximately 1 Hz, can theoretically reach power density limits as high as $343mW/cm^3$, and practically up to $19mW/cm^3$.Daily activities such as walking have shown great potential for generating significant power. This underscores the importance of implementing energy harvesting technologies to provide electricity for low-powered devices, turning users into both producers and consumers of energy. The frequency of human movements generally remains below 10 Hz, with step frequencies during walking varying from 1.2 to 2.2 Hz, depending on the average walking speed. Various locations on the body, such as the ankle and knee, display higher accelerations, making them more energetic regions for power generation. Kinetic energy harvesters, employing piezoelectric, electromagnetic, electrostatic, or magnetostrictive mechanisms, play a crucial role in converting this kinetic energy into electrical power.

3. IMPLEMENTATION AND WORKING PRINCIPLE

3.1 Shape of the Tile

To understand and implement the optimal shape of the tile, Finite Element Analysis (FEA) analysis was undertaken on the Autodesk Inventor software, experimenting with the two most common shapes of tiles, square and triangle. [4] This analysis aids in identifying the most suitable shape that optimizes energy harvesting and ensures structural integrity, guiding the iterative design process for creating an efficient and durable tile.

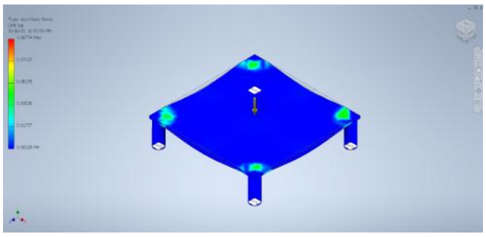


Fig -3.1: Square analysis using force in center

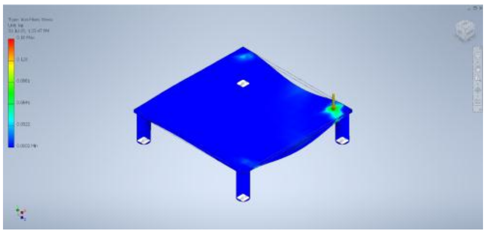


Fig -3.2: Square analysis using force at vertex

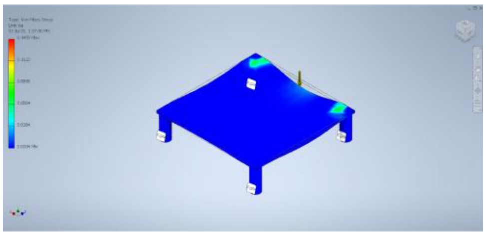


Fig -3.3: Square analysis using force along edge

For the analysis the side of each figure was given a length of 17.5 inches, the thickness of each plate is 10mm and the stilts are 30mm long. The material chosen was plywood. The weight assigned for each force was 55N.

Stress, strain and displacement analysis of a square: As seen in the Images above, when a square tile supported by stilts (to be imagined as columns with piezo sensors beneath them) is compressed at different areas on the surface, the compression of the upper plate differs. Only when one steps in the center of the tile (Fig 3.1) are all the stilts compressed and engaged, hence only then all four piezos are in use. On the other hand if one steps on the corner or along the side of the square (Fig 3.2 and 3.3), at most only 3 piezos are engaged and 2 sides undergo compression.

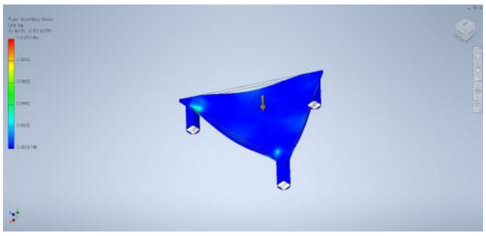


Fig -4.1: Triangle analysis using force in center

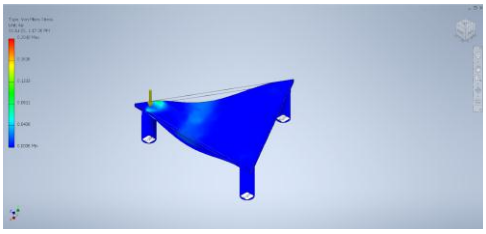


Fig -4.2: Triangle analysis using force at vertex

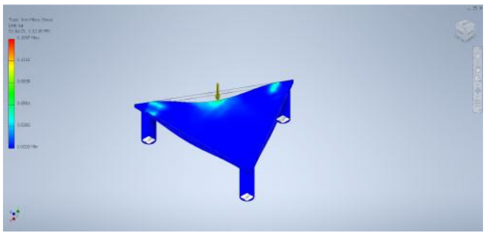


Fig -4.3: Triangle analysis using force along edge

Stress, strain and displacement analysis of a triangle: On the other hand, on analyzing the triangular model, wherever a human where to step, in the center, on the perimeter or at the vertices, each steps allows for all piezoelectric sensors to be engaged at once, seen by the compression of all three sides of the triangle. Moreover, in square tiles, stress accumulates at the corners, which could lead to uneven energy generation or structural issues. Also due to a triangles three-sided structure, forces are distributed more evenly, making them less prone to wobbling or instability. Triangular tiles' robust structural properties make them more resistant to external pressures, impacts, and load distribution. This is especially relevant in practical applications where the tiles may experience varying levels of stress.

As a result, the triangular shape was chosen for the tiles over the square shape to ensure efficient generation of energy from each sensor for each step.

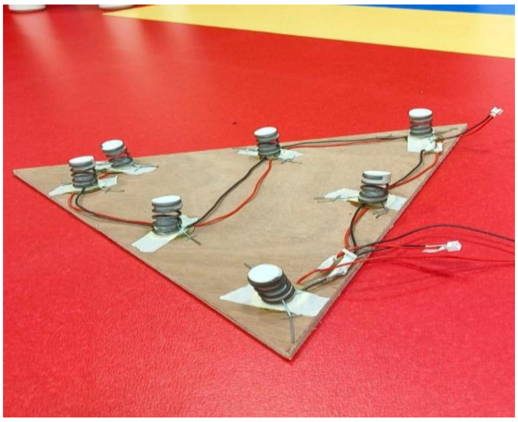


Fig -5: Final Tile shape

The size of the tile is according to the spatial structure of the walking cycle and normal range of motions assuming a velocity of 1.3m/s as seen below.

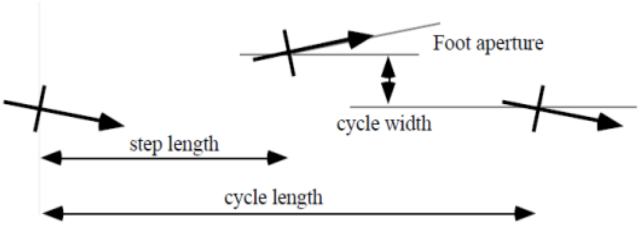
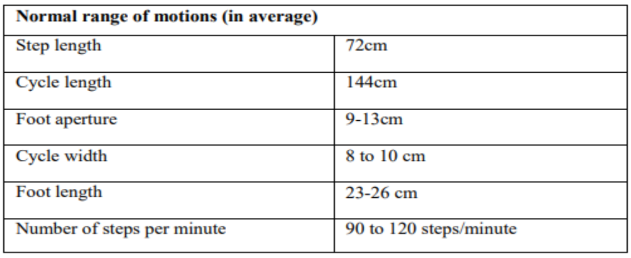


Fig -6: Walking Cycle Diagram



Normal range of motions (in average)	
Step length	72cm
Cycle length	144cm
Foot aperture	9-13cm
Cycle width	8 to 10 cm
Foot length	23-26 cm
Number of steps per minute	90 to 120 steps/minute

Fig -7: Normal Range of Motions

3.2 Piezoelectric Sensors

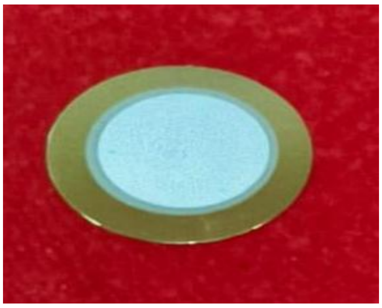


Fig -8: Piezoelectric Sensor

Piezoelectric sensors are an electrical component that converts a mechanical or thermal input into an electrical signal.. As the tile is compressed due to pressure exerted by the human body while walking the sensor comes into contact with the projections on the tile surface. This allows for polarization of these materials, resulting in the distribution of electrical charges across their surface.

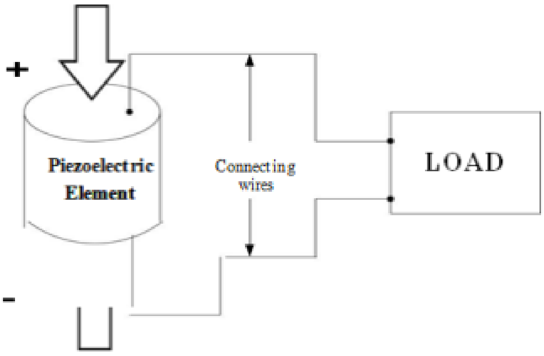


Fig -9: Functioning of Piezoelectric sensor

Piezoelectric sensors are the main device used in the prototype for the conversion of energy. There are many forms of piezoelectric materials, the one used being copper with a diameter of 35mm and output voltage of 1.1v. Due to their smaller size, higher energy density, simple structure and low cost they were utilized in this model. [5] Moreover they do not require a separate initial voltage source, allowing them to be easily incorporated into systems in a compact manner required for such tiles. Moreover they are much more sensitive, as studied for producing power from smaller scale vibrations like footsteps. As a result they have been incorporated into this prototype over other potential choices like electromagnetics and electrostatic transducers. Each sensor has been joined in the tiles using a series connection, resulting in an theoretical total voltage of 6.6V across each tile. Contrastingly had they been in a parallel connection the total voltage in the circuit would have only been 1.1v.

3.3 Outside Material

The selected material for the pavement must be robust and durable. Tensile strength and Compression strength assessment is necessary to determine the material's capacity to withstand compressive forces to bear the weight and from pedestrians without crushing. Elongation at break evaluation is essential to understand the material's flexibility and resilience over time. Poisson's ratio analysis is necessary to assess the material's lateral deformation response under stress and ensures the tiles can efficiently convert mechanical stress into electrical energy without excessive energy loss. Finally the material selected must also be cost effective to ensure the scalability and viability of the energy tiles on a larger scale. Hence a comparative study was undertaken to decide on the material to be used for the prototype.

Table -1: Material Property comparison

Tensile Strength	**MDF**	**Wood**	**Metal (3003 Aluminum)**
Compressive strength	18 Mpa	80 Mpa	110 Mpa
Poisson's Ratio	10 Mpa	40 Mpa	70 Mpa
Elongation at Break	0.25	0.37	0.33
Cost effectiveness	MDF is generally the most cost-effective option among the three materials	Wood can be relatively cost-effective, especially when sourced from sustainable forestry	Aluminium tends to be the most expensive option among the three materials.

As seen on comparison, although Aluminium 3003 had overall best durability and elongation at break, due to its high costs in the markets wood was selected as the material for this prototype. More over the ease of working with wood in terms of customization and adaptation to specific project requirements using basic hand tools and woodworking skills. Hence ply wood triangle sheets of side length 444.5mm and width of 10mm were used as the top and base for each tile. Each piece was lazer cut to ensure precision in the sizing of each tile.

3.4 Mid layer Material

Between both plates of wood, a combination of springs and foam was used for the crucial purpose of allowing the transfer of pressure from the surface of the tile to the piezoelectric sensors on the bottom surface.

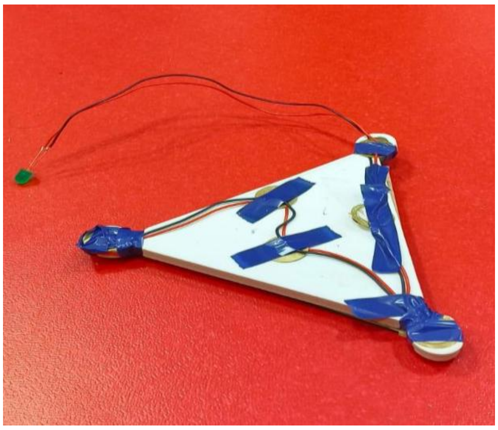


Fig -10: Pre-Prototype – MDF and Foam

It was realized that by only using foam in the pre - prototype, under deformation caused by pressure the tile took longer to restore its original shape. Moreover, foam's ability to absorb impact rather than dissipate the vibrations produced might inadvertently dampen the mechanical stress applied to the piezoelectric sensors, resulting in reduced energy conversion.

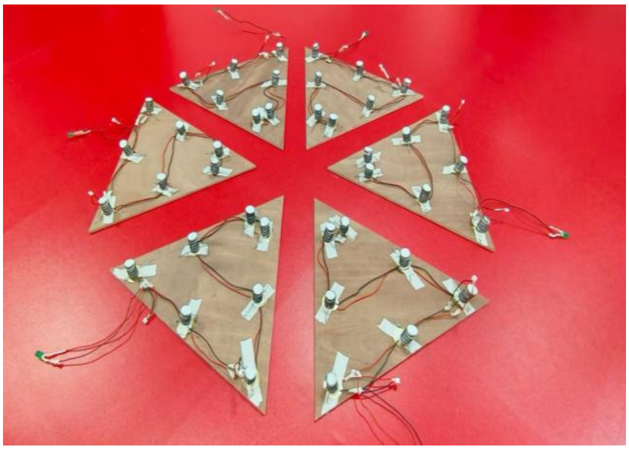


Fig -11: Tiles only with Spring

Conversely, the use of only springs in the tile might lead to unmitigated transfer of footfall pressure to the piezoelectric sensors. This might subject them to abrupt mechanical force, potentially leading to premature wear and damage. Additionally, it could create an uncomfortable walking surface for pedestrians where this is an essential consideration.

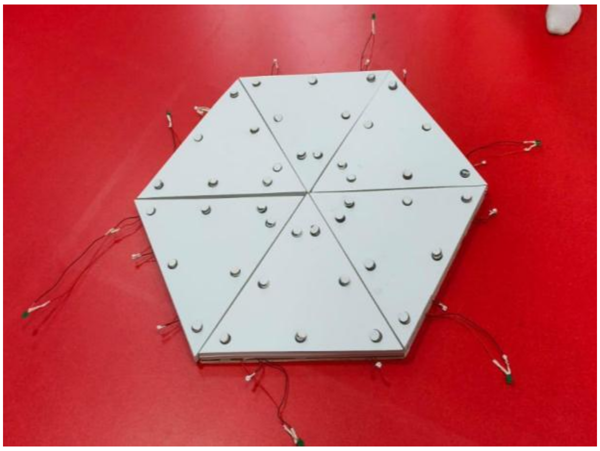


Fig -12: Final Tiles with Spring and Foam

Hence a combination of both materials was used in each tile. 10mm foam was used to prevent wear and tear of the sensors and protect them from excessive mechanical damage while also providing comfort in each step. While the 3mm diameter springs were kept slightly longer than the foam layer, and also directly above each piezo to ensure the mechanical pressure was directly transferred to the sensor to ensure increased energy production.

4. RESULTS

To understand and analyze the effectiveness of each tile separately on undergoing mechanical stress, physical testing was carried out on the prepared tile. 5 test subjects of different weights were asked to walk on the tile for different lengths of time. The table below records the variations in voltage generated by each subject.

Table -2: Recorded voltage from each Test

Subjects	**Weights**	**Time**			
		5s	**10s**	**15s**	**30s**
1.	**55kg**	**4.4**	**4.8**	**5.0**	**5.1**
2.	**60kg**	**6.4**	**6.6**	**6.7**	**7.2**
3.	**62kg**	**6.2**	**6.8**	**7.1**	**7.5**
4.	**72kg**	**6.9**	**7.3**	**7.6**	**8.0**
5.	**100kg**	**9.8**	**10.2**	**10.2**	**10.6**

To better understand the variation of time with the voltage generated a graph of the results has also been presented.

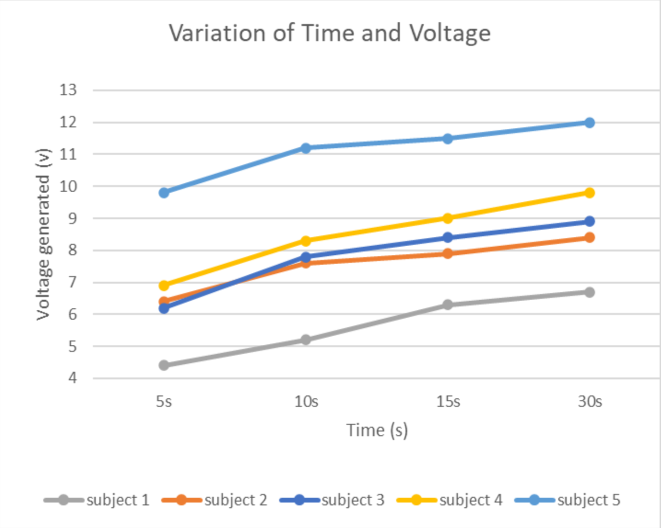


Chart -1: Variation of Time with Voltage Generated

The voltage generated depends on the force that is being applied to the electric tile. In theory when a bigger person pumps on this electric tile, the voltage that is generated is higher compared to the smaller person. There should hence be a linear relationship between the two. This is solidified by the fact that for each time band in the graph the voltage generated by subject 1 is greater than that of 2, whose weight is higher. At the same time theoretically the time the force is applied for should also lead to a higher yield of voltage. This is also proved through the testing as with an increase in time there is a linear increase in the voltage generated.

5. FUTURE SCOPE

The future scope of the "PowerWalk" project holds immense potential for growth and impact. Advancements in materials science could lead to the development of even more efficient piezoelectric materials with higher energy conversion rates, enabling increased electricity generation from footstep-generated mechanical stress. Additionally, exploring novel materials with superior mechanical properties could enhance the durability and longevity of the tiles, allowing them to withstand more extensive and diverse urban environments. The implementation of "PowerWalk" can extend beyond city pavements to encompass various high footfall areas, such as shopping malls, stadiums, airports, and public transportation hubs, exponentially multiplying its energy-harvesting capacity. Another option could be the installation in bumpers on roads where the pressure of the car remains the highest. As "PowerWalk" tiles continue to be deployed in urban landscapes worldwide, they could collectively contribute to significant reductions in carbon emissions by generating clean, renewable energy from otherwise wasted kinetic energy. Embracing this sustainable technology on a larger scale has the potential to revolutionize urban energy consumption and promote a greener and more environmentally conscious future for our cities.

5. CONCLUSION

This project designed tiles that harvest kinetic energy off of pedestrian walking and also provides a comfortable surface for pedestrians as well. The proposed pavement tile consists of piezoelectric materials sandwiched between layers of plywood, foam and springs. The study examined different designs of tiles, materials, connectors and layers to obtain the optimum condition. The results show that the arrangement of sensors on the outer boundary of the tile covered with sheet of foam can distribute the loads better and subsequently, generate higher voltage. The study recommends that it is especially suited for implementation in crowded areas as most of the kinetic energy of waking people is wasted, even though it can be harvested through an energy-harvested tile.

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BIOGRAPHIES

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